

Keil

A N
INTRODUCTION
TO THE TRUE
ASTRONOMY:
O R,
ASTRONOMICAL LECTURES,
Read in the
Astronomical School
O F T H E
U N I V E R S I T Y o f O X F O R D.

By J O H N K E I L L, M. D. Fellow of the *Royal Society*,
and Professor of *Astronomy* in that University.

*The Works of the Lord are great, sought out of all them
that have Pleasure therein, Psal. cxl. 2.*

The T H I R D E D I T I O N, Corrected.

L O N D O N:

Printed for HENRY LINTOT, at the Cross-Keys,
against St. Dunstan's Church in Fleet-street.

MDCCXXXIX.



A N
INTRODUCTION
TO THE
ASTRONOMY
OF
ASTRONOMICAL LECTURES
Read in the
Astronomical School
OF THE
UNIVERSITY OF OXFORD

By JOHN KEEL, M.D. Fellow of the Royal Society
and Professor of Astronomy in the University

The Fourth Edition, Corrected.

L O N D O N:
Printed for H. and J. Baskett, in the Strand,
against St. Dunstons Church in Fleet Street.

MDCCLXXII.





TO HIS GRACE

J A M E S,

Duke of *CHANDOS*.

May it please your GRACE,



AMONG all the Mathematical Sciences, which have been continually improved, and are daily improving in the World, the first Place has, as it were, by general Consent, been always given to Astronomy. And such has been either the good Fortune of the Science, or the Virtue of Mankind, that the greatest and most eminent Persons in all Ages and Nations, have been Patrons and Encouragers of this Study above all others.

DEDICATION.

MAY it please your Grace, therefore, to take this Book into your Protection, since whatever may be wanting, either in the Work or the Author, to recommend it to your Favour, will abundantly be supplied by the Dignity of the Subject.

FOR to whom can I so properly send a Treatise of the Stars and heavenly Motions, as to a faithful and zealous Servant of that heavenly King, who knoweth the Number of the Stars, and calleth them by their Names? So remarkable is your Grace's Zeal for the Service and Honour of God, that you took particular Care to adorn his House, before you would lay the Foundation of your own. Nor did your Care extend only to the Ornaments of the Temple, but likewise, and more especially, to the Decency of the Worship: You call'd Musick in to excite Devotion; Musick being the Delight and Employment of the heavenly Choir.

YOU, my LORD, are the publick and standing Mark of all Mens Admiration, the beautiful Pattern which all desire to imitate, tho' few can hope to equal. In publick Affairs, what Statesman more able? In domestical Management, what private Man more expert? In the constant stating and exact keeping of Accompts, nobody more provident, nobody more frugal:

DEDICATION.

*frugal: In Expences, nobody more liberal:
In Largesses, nobody so magnificent.*

So great is your Affection to Learning and the Learned, that while you make yourself Master of every Art, you give Matter and Encouragement to every Artist. To the particular Science which is the Subject of this Book, your Grace is so eminent, so beneficent a Patron, that in the stately and beautiful Structure of Cannons, Astronomers will find every Thing for the Improvement of their Knowledge; Instruments worthy of the Science, and an Observatory worthy of its Lord.

THE Book I now present is a Translation of those Astronomical Lectures, which were honoured with your Grace's Name at their first Publication, in the Language they were read in at the University of Oxford. The Version was made at the Request, and for the Service of, the fair Sex, and particularly for the Service of the great Ornament of her Sex, the Duchess of Chandos. It is no Flattery to the Ladies, to say, that such of them as delight in Arts and Sciences, as to Quickness of Perception, and Delicacy of Taste, are equal, if not superior, to Men; and it is no Affront to the most refined of either Sex, to say, there is not a finer Genius than my Lady Duchess.

DEDICATION.

MAY every Star in Heaven shed its kindest Influence on both your Heads. And may you long continue to enjoy that Affluence, which, like the Rays of the Sun, scatters Light and Warmth to all round you.

THIS, my LORD, is a general Wish, because it is for the general Good of Mankind, particularly of him who is, with the deepest Sense of Gratitude,

Your Grace's

Most faithful and

Most humble Servant,

JOHN KEILL.

THE



THE PREFACE.



AMONG all the Gifts and Benefits the most bountiful God has most plentifully bestowed on Mankind, those are in the first Place valuable, which consist in the Improvements of the Mind by Arts and Sciences. And as among the Sciences, there are none which *Astronomy* comes behind upon the Account of its Antiquity, and the Pleasure that attends the Study of it; so it will yield to none of them on the Account of its Usefulness, and the Advantages it affords to human Life. By it we discover the wonderful Harmony of Nature, wherewith the Frame and Structure of all created Beings are link'd and knit together, to constitute the great Machine of the Universe. *Astronomy* teaches us to observe and discover the Motions of the heavenly Bodies, and it weighs and considers the Vigour and Force by which they circulate in their Orbs. It is a Science, which the greatest Heroes, from the Beginning of the World, have taken Pleasure to study and improve; so that it was always esteemed as a Science fit for Kings and Emperors to employ themselves in. On which Account, the *Chaldean* Wise-men and Philosophers were always revered and favoured by the antient Kings, who thought it absurd that any should govern the World, who knew not what the World was.

THE Excellency of this Science appears from this, that there is no Knowledge which is attain'd by the Light of Nature, that gives us truer and juster Notions of the Supreme and Almighty God

the Maker of both Heaven and Earth, than it does. None furnishes us with stronger Arguments by which his Existence is demonstrated; nothing shews more his Power and Wisdom, than the Contemplation of the Stars and their Motions. That Prophet as well as King, the Holy *David*, tells us, that *The Heavens declare the Glory of God, and the Firmament sheweth his Handy-Work. And again, The Heavens declare his Righteousness, and all the People have seen his Glory.*

MARCUS Tullius Cicero, who was guided only by the Light of his own Reason, had the same Sentiments. *Nothing, says he, is more evident, nothing plainer, when we look up to the Heavens, and contemplate the Bodies there, than that there is a Deity of most excellent Wisdom, who governs them.* What is there that more ravishes the Mind of Man into an Admiration, Reverence and Love of God, than so many and so great Bodies endowed with heavenly Light, most beautiful to the Eye, and when contemplated, most delightful to the Understanding? Their mutual Intercourses, most regular Motions, their certain and determined Circulations, and their Returns and Periods settled by a divine Law, in an admirable Harmony, make manifest to us the immense Power, Wisdom, and Providence of their Maker; which when we consider, we must necessarily acknowledge, reverence and celebrate the Author and Contriver of all these Things.

BESIDES, *Astronomy*, with its sublime Speculations about so many and so large Bodies, and at such immense Distances, does wonderfully please and recreate the Mind.

ASTRONOMY, for the Certainty and Evidence of its Demonstrations, is not inferior to *Geometry*; its Usefulness is manifold, and the Amplitude of its Subject is so large, that it comprehends nothing less than the World itself. For as, among all the liberal Sciences, there are none that contemplate Objects more in Number, greater in Quantity, or at longer Distances from us, than *Astronomy*; so likewise there are none in which there still remain fewer.

fewer Difficulties to be explained, Objections to be answered, or Scruples to be removed, than there are in *Astronomy*; and no Science has yet attained so great a Degree of Perfection as it has.

IN most of the other Arts there are several inextricable Labyrinths; many strange Objections are raised, and unanswerable Arguments, which do so confound the Mind, that like thick Clouds, they stop all further Prospect and Discovery. But the Motions of the heavenly Bodies are now certainly known, and their Causes demonstrated, and the Reason of all the *Phænomena* of the Heavens are exactly understood.

THE smallest Stars we can see, tho' they be at an unmeasurable Distance from us, yet have their Longitudes and Latitudes exactly determined, their proper Places settled, and are all reduced into Catalogues; tho' at the same time the Science of *Geography*, or a Description of our own Habitation, is so imperfect, that we have an exact Determination of the Longitudes and Latitudes of but a very few Places; there still remaining many *Unknown Lands* and Countries, that have not as yet been discovered: And there are now great and far extended *Continents*, of which we scarcely know any thing besides their Coasts and Shores. And what is still more strange, in our little Provinces and Counties which we daily travel over, there are many Towns and Cities whose Positions are still uncertain; as is plain from the many *Geographical* Maps of them, which contradict each other.

THE *Astronomers* foretel, for many Ages to come, the Eclipses of both Sun and Moon, their Quantities and Durations; the Conjunctions, Oppositions and mutual Aspects of the Planets, and what will be the Distances of all the Stars from the Pole at any Time: Whereas there is no Man so well skilled in *Meteorology*, as can certainly foretel what will be the State and Condition of our Atmosphere for the very next Day, and yet it reaches but a few Miles from us: We are unable to judge whether we shall have fair Weather or foul, calm or stormy,

stormy, or even so much as to foresee from what Point the Wind will blow. And this is no Wonder, since the Causes from whence those Effects arise are unsearchable.

No *Philosopher* has ever yet discovered the Figures of the small Parts of Matter, or the Texture, Intervals, Form and Composition of the Parts of the most common Plant. Nor has any Physician yet found out the Reason of the Virtues and Operations, by which their Medicines affect human Bodies. And even in all animated and vegetable Bodies, the Fountain and first Principle of Life and Action is unsearchable, and looks like a Mystery much beyond the Reach of our Understanding, which Knowledge perhaps, in this Life, is never to be attained. But *Astronomers* in their proper Science meet with no such Difficulties; they contemplate not the Natures, but the Motions of the celestial Bodies, and they clearly account for the *Phænomena* or Appearances that arise from thence: They not only determine what sort of Motion the Planets have, and in how large a Compass they circulate; but they likewise shew us the crooked Tracts in the immense Regions of Space which the wandering Comets take: They can give us the *Geometrical* Properties of their Orbits, and the Laws which they observe in describing them. The *Astronomers* are not ignorant, where or when the Planets are at their farthest Distance from the Sun, and participate the least of his Heat and Light; from whence they return, and are constantly quickened in their Motions by the Sun, who draws them towards himself, 'till they come to those Parts of Space, where they make their nearest Approach to him, enjoy most of his Heat and Light, and are actuated by the greatest Force of their own Gravity.

MOST of the Discoveries we have related, were known to the *Astronomers* of former Ages. But our Times, and this our Country of *Britain*, have had the Happiness to produce a *Genius* of a divine Nature, and extraordinary Qualities; I mean the great Sir *ISAAC NEWTON*, who, besides his innumerable

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merable other wonderful Inventions, has discovered the Fountain and Spring of all the celestial Motions, and the great Law, which is universally diffused through the whole System of Nature, which the Almighty and Wise Creator has commanded all Bodies to observe, *viz.* That every Particle of Matter attracts each other in a reciprocal duplicate Proportion of its Distance.

THIS Law is, as it were, the Cement of Nature, and the Principle of Union, by which all Things remain in their proper State and Order; it detains not only the Planets, but the Comets within their due Bounds, and hinders them from making Excursions into the immense Regions of Space; which they would do, if they were only actuated by a Motion once implanted in them, which naturally they would always preserve, according to the principal Law of Motion.

WE are obliged to the same Gentleman for the Discovery of the Law that regulates all the heavenly Motions, sets Bounds to the Planets Orbs, determines their greatest Excursions from the Sun, and their nearest Approaches to him. To this sublime Genius we owe, that now we know the Cause why such a constant and regular Proportion is observed, by both primary and secondary Planets, in their Circulations round their central Bodies, in comparing their Distances with their Periods; and why all the celestial Motions are still continued in such a wonderful Regularity, Harmony and Order. The same incomparable Person, having a complete Knowledge of the Laws of Nature and Motion, has from them furnished us with a new Theory of the Moon, which accurately answers all her Inequalities, and accounts for them by the Laws of Gravity and Mechanism; so that now the Moon's Place, computed by the Rules of this new Theory, does not sensibly differ at any Time from what it is observed to obtain in the Heavens, which does exceed the Hopes and Expectations of our *Astronomers*; so that we have now a Prospect of improving our Navigation, by finding from Observations

servations of the Moon, the Longitude of a Ship at Sea: A Problem of great Use, whose Solution is much to be desired; and for which there are very ample Rewards allowed.

T H E R E is nothing that does more shew the Force and Penetration of human Understanding, than these great and wonderful Discoveries. There is no more certain Way of comprehending the prodigious Bulk of the whole mundane Fabrick, or the amazing Beauty of so divine a Structure, and the infinite Wisdom of its divine Contriver, than by considering these Laws which are lately discovered. From them we learn to have a most noble and magnificent Notion of the whole System of Nature. Now we are assured, that this Earth we inhabit, is but a small and inconsiderable Part of a glorious Fabrick; since there are almost infinite Worlds, created by a Supreme and an Almighty Being, which are prodigiously larger than ours, in the disposing and governing of which, the same Being exercises his infinite Power and Wisdom. *It is he who spoke the Word, and the Heavens were made. He commanded, and they were created. He hath made them fast for ever and ever. He hath given them a Law which shall not be broken.*

ASTRONOMY is not only useful, as it improves the Mind, and by its most delightful Speculations, increases the Force and Penetration of the Understanding: But it is likewise a considerable Help to the perfecting of other Arts and Sciences. In how great Darkness would the *Geographers*, the *Chronologists* wander, were they not assisted with Light from *Astronomy*? To it is owing, that we know the Figure and Magnitude of the Earth, and find out the Situations and Distances of Places. We learn from it the true Measure of the Year, and can give an Account of Actions, according to the true Order of the Times in which they happen'd. Hence is evident, how useful *Astronomy* is to human Affairs; for without it, we could have no *Geography* nor *Chronology*, and consequently no certain Account of History.

B U T

BUT among all the Arts and Sciences, there is none that has received greater Improvements from *Astronomy*, than *Navigation* has done; for by our Knowledge in it, we can carry our Ships through the vast Ocean in a right Course, though there is no Tract to be seen, and visit the utmost Regions of the Earth. Hence arise the Advantages of Trade and Commerce; so that whatever Things other Countries afford, that are either precious or delightful, we receive and enjoy without the Inconveniences of intemperate Heats or Colds, to which those Countries are liable. It is owing to our Skill in Navigation, that our *British* Monarchs have obtained the Sovereignty of the Seas: So that there is no Nation, at what Distance soever, but what are kept from doing Injuries to our Countrymen, by the Terrors of a *British* Fleet.

As the Art of Sailing does, in a great measure, depend on the Knowledge of the Stars; so the impetuous and ambitious Desires of Kings and Princes, to discover unknown and foreign Countries, inclined them to cultivate *Astronomy*. The first and chief of all the Sailors was Neptune, who, upon the Account of his Skill in this Art, was celebrated as God of the Ocean. His Son Belus, being an *Astronomer*, by his Knowledge therein, carried the Inhabitants of *Libya* into *Asia*, where he instituted Colleges of *Astronomers*; for *Diodorus*, in the first Book of his Histories writes thus: *It is reported, says he, that the Egyptian Belus, the Son of Neptune and Libya, brought a Colony to Babylon; and there he instituted Priests, whom the Babylonians call Chaldeans; who, after the manner of the Egyptians, were to observe the Stars.* Before his Time, there was *Atlas* King of *Mauritania*, a great *Astronomer*, who first shewed us the Doctrine of the Sphere. And therefore *Virgil* introduces *Iopas* singing, what *Atlas* had taught Mankind,

————— *Docuit quæ maximus Atlas,
Hic canit errantem Lunam, Solisque labores.*

So *Uranus*, King of the Country situated on the
Shore

Shore of the *Atlantick* Ocean, for his Skill in *Astronomy*, is said to have been descended from the Gods. *Zoroaster* a *Persian* Philosopher, is celebrated by all Antiquity, as a skilful *Astronomer*. And the Honour and Dignity of this Science was had in so great a Reputation, as to be called the *Royal Science*, being that Kings were most delighted by it above all others. For the Kings of *Africk* and *Syria* first invented and improved it, and that long before it was known in *Greece*. This *Plato* acknowledges in his Dialogue, which he calls *Epinomis*. The first, says he, who observed these Things, was a Barbarian, who lived in an antient Country, where, upon the Account of the Clearness of the Summer Season, they could first discover them, such as *Egypt* and *Syria*, where the Stars are clearly seen, there being neither Rains nor Clouds to hinder their Prospect. And because we are more remote from this Summer Clearness of Weather than the Barbarians, we came later to the Knowledge of these Stars. So *Lucian* tells us, That the *Ethiopians* first took Notice of the heavenly Motions, and by finding the Causes of the Lunations, they knew that the Moon had no proper Light of its own, but borrow'd it from the Sun. However, it is certain, that *Astronomy*, from the very Beginning, was cultivated and improved by the Eastern Nations. For if we may believe *Porphry*, when *Alexander* took *Babylon*, *Callisthenes*, at the Desire of *Aristotle*, carried from that City the Observations of 1903 Years, which brings the Beginning of these Observations to 115 Years after the Flood, and 15 Years after the Building of *Babel*. *Pliny* in his Natural History relates, that *Epigenes* affirmed, that the *Babylonians* had Observations of 720 Years, all graven upon Bricks. And *Achilles Tatius*, in the Beginning of his Introduction to *Aratus's Phænomena*, informs us, " That the Egyptians were the first who measured the Heavens
 " and the Earth; and their Science in this Matter
 " was engraven on Columns, and by that means
 " delivered to Posterity. Yet the *Chaldeans* take the
 " Honour of the Invention to themselves, and
 " ascribe

“ ascribe it to *Belus*.” The *Greeks* had all their *Astronomical* Learning from *Egypt*: For *Laertius* owns, that *Thales*, *Pythagoras*, *Eudoxus*, and many others, went to that Country to be instructed in the *Sidereal Science*: These Men were not only the first, but the greatest Philosophers that *Greece* produced: And from the same Author we know, that they who staid longest in that Country, were most famous for their Skill in *Geometry* and *Astronomy*, after they returned home: So *Pythagoras*, who lived in Society with the *Egyptian* Priests seven Years, and was initiated into their Religion, carried Home from thence, besides several *Geometrical* Inventions, the true System of the Universe; and was the first that taught in *Greece*, that the Earth and Planets turn’d round the Sun, which was immoveable in the Center; and that the diurnal Motion of the Sun and fixed Stars was not real, but apparent, arising from the Motion of the Earth round its Axis. At that Time nobody was esteem’d as a Philosopher, but who was well acquainted with the mathematical Sciences.

BUT these Sciences were soon neglected by the Philosophers that came after them, who much degenerating from their Predecessors, had so little Care and Concern for the mathematical Sciences, especially *Astronomy*, that of all the Observations of Eclipses, for the Space of near 2000 Years, that were sent from *Babylon* by *Callisthenes*, *Ptolemy* could recover but a very few, the rest being lost by the Carelessness, Negligence, and want of Skill of those Men, who should have preserv’d them. For these Pretenders to Philosophy, having no Concern for the useful Parts of it, spent their Time about Trifles, and Disputes of no Value, and in endeavouring to find out Sophisms, whereby they would impose upon their own, and the common Sense of all Mankind: Such were *Zeno*’s Arguments against Motion, and most of the Philosophers Disputations against the Divisibility of Matter *in infinitum*; whereas a little Knowledge of *Geometry* would easily have dissolved all the Difficulties they could raise.

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raise. But tho' *Astronomy* was thus banished out of the Schools of the common Philosophers, yet it was received and cultivated by some, tho' but a few, especially by the *Pythagorean* Sect, which flourish'd in *Italy* many Years, among whom was *Philolaus* and *Aristarchus Samius*. The *Ptolemies*, Kings of *Egypt*, were also great Patrons of Learning, they founded an Academy for *Astronomy* at *Alexandria*, which furnished us with great Men, the chief of whom was *Hipparchus*, who, according to *Pliny*, undertook a Business which would have been a great Work for a God to perform, that is, to number the Stars, and leave the Heavens for an Heritage to all that come after. This Man foretold the Eclipses of both Sun and Moon for 600 Years; and upon his Observations is founded that precious Work of *Ptolemy*, which he call'd his *μεγάλη σύνταξις*, or his great Construction; for from them he gathered the Precession of the Equinoxies, and the Theory of the Planets.

WHEN *Egypt* was conquered by the *Saracens*, and *Alexandria* reduc'd under their Jurisdiction, the Conquerors took *Astronomy*, with the rest of the Liberal Arts, under their Protection; and took care that most Part of the Books concerning the Liberal Arts and Sciences should be translated from the *Greek*, into their own *Arabian* Language.

THE *Saracens* passing from *Africk* into *Spain*, and having a Commerce with the Western *European* Nations, imparted to them the Science of *Astronomy*, which before was almost lost in *Europe*; so that about the Year 1230, at the Command of the Emperor *Frederick*, *Ptolemy's* *Almagest*, or his great *Syntaxis*, was translated from the *Arabick* into *Latin*.

AFTER that Time, *Astronomy* received many Improvements from the Patronage of the greatest Princes, and the Labours of the most celebrated Philosophers; among whom, in the first Place, is to be nam'd *Alphonsus* King of *Castile*, who is never to be forgotten, on the Account of the *Astronomical* Tables, call'd after his Name. *Nicolaus Copernicus* was not only a diligent Observer, but also a Restorer of the ancient *Pythagorean* System.

System. Prince *William*, Landgrave of *Hess*, who procur'd Quadrants and Sextants much larger than what were formerly us'd, to observe the true Places of the Stars: This Prince's Observations are published by *Snellius*. Sir *Henry Savill* was most skilful both in *Astronomy* and *Geometry*, who is ever to be honoured for his Munificence in founding our two Professions of *Astronomy* and *Geometry* in the University of *Oxford*, and endowing them with ample Salaries; upon which Account, and many other Benefits he bestowed on the learned World, he will always be had in Remembrance with the greatest Respect. That Noble Dane *Tycho Brahe*, who for his Skill in observing, was superior to all that went before him; and who, for the Furniture of his Observatory, exceeded even Princes and Kings: He published a Catalogue of 770 fixed Stars, which he had diligently observ'd. *John Kepler*, a most excellent *Astronomer*, by the Help of *Tycho's* Labours, found out the true System of the World, and the Laws the Celestial Bodies observe in their Motions, with which he vastly improv'd *Astronomy*; his excellent Works are well known to the learned World, and will ever shew how much he is to be praised. *Galileus*, the *Lyncian* Philosopher, who first applied a Telescope to the Heavens, and by its Means discover'd a great many new surprising *Phænomena*; as the Moons or Satellits of *Jupiter*, and their Motions; the various Phases of *Saturn*; the Increase and Decrease of the Light of *Venus*; the mountainous and uneven Surface of the Moon; the Spots of the Sun; and the Revolution of the Sun about his own Axis; all which were first observ'd by this great Philosopher.

I should much exceed the Bounds of a Preface, if I should name the rest of the great Improvers of our Art, with the Praises that are due to them; particularly, *Hevelius*, who has given us a Catalogue of the fixed Stars, much larger than *Tycho's*, composed from his own curious Observations. The most illustrious Gentlemen, Messieurs *Hugens* and *Cassini*, who first saw the Satellits of

Saturn, and discovered his Ring: *Gassendus*, *Horrox*, *Bullialdus*, *Ward*, *Ricciolus*, and many other *Astronomers* of great Renown. But we have one here, who on Account of his great Merits in *Astronomy*, does excel them all, that is, the most eminent and learned Dr. *Edmund Halley*, *Savillian* Professor of *Geometry* in this University, my most friendly Colleague; to whose Labours *Astronomy* owes many, and those not small Improvements; in him there shines out together (which I know not if they are to be found in any other Person to such a Degree) the greatest Dexterity in Practical *Astronomy*, and a most profound and exquisite Skill in *Geometry*; which will appear by his *Astronomical* Tables, which he is shortly to publish; for they will far excel all others that ever were, or perhaps ever will be published.

I could name many others of our own Countrymen, who have done much Service towards the Improvement of *Astronomy*; but we must not pass over in Silence the Labours of the celebrated Royal Professor, the late Mr. *John Flamsteed*, who with indefatigable Pains, for more than 40 Years, watched the Motions of the Stars, and has given us innumerable Observations of the Sun, Moon and Planets, which he made with very large Instruments, exactly divided by most exquisite Art, and fitted with telescopial Sights. Whence we are to rely more on the Observations he hath made, than on those that went before him, who made their Observations with the naked Eye, without the Assistance of Telescopes. The said Mr. *Flamsteed* has likewise composed the *British* Catalogue of the fixed Stars, containing about 3000 Stars, which is twice the Number that are in the Catalogue of *Hevelius*; to each of which, he has annexed its Longitude, Latitude, Right Ascension, and Distance from the Pole; together with the Variation of Right Ascension and Declination, while the Longitude increases a Degree. This Catalogue, together with most of his Observations, is printed on a fine Paper and Character, at the Expence of the late Prince *George of Denmark*; but Mr. *Flamsteed*, before he died, had near
finished

finished another Edition of them at his own Expence, which I am told will be shortly published.

AMONG so many Helps and Advantages towards the Understanding of *Astronomy*, there was still wanting an universal and complete Theory of the celestial *Phænomena*, explained according to their true Motions and physical Causes. But this Work has been lately performed, finished, and published by the late Dr. *Gregory*, the great Honour of our Profession, and my Preceptor, whom I ought always to remember with Gratitude; for it is owing to him, if I have made any Advances in this Study.

IN the mean time it is to be acknowledged, that this Work does not seem to be suited to the Capacity of young Beginners; for it contains many Things which require an Insight into deep *Geometry*, so as to be clearly understood; which Skill is seldom to be met with in young Men, who are for all that capable of learning the Elements of *Astronomy*. Besides, the celestial Motions and their physical Causes are always jointly explained; which two Things, when they are to be learned by Beginners, distract them too much, and make the Doctrine difficult. Therefore I thought it more advantageous to the Learner, first to explain the Motions, and give an Account of the *Phænomena* that arise from these Motions; which when once understood, there will be an easy Admission into the Knowledge of physical Causes.

FOR which purpose, I composed the following *Lectures*, which I read in the *Astronomical School at Oxford*, as my Duty obliged me: In them I have taken some Pains, that all the celestial Motions may be clearly explained, and the Reasons of the *Phænomena*, which arise from those Motions, be given. But particularly of those which are to be understood by the Help of a few Propositions of the Elements of *Geometry*. And therefore I would advise our young Beginners, who desire to learn *Astronomy*, that they would place *Euclid's Elements* before them, when they read these *Lectures*, and consult them when they find any Propositions quo-

ted by us. Those we chiefly use, are but few in Number; such are the 4th, 5th, 8th, 13th, 15th, 27th, 29th, 32d, and 47th of the first Element. The 16th, 18th, 20th, 31st, 35th, 36th, 37th of the 3d Element: Also the 4th, 5th, and 6th of the 6th Element; besides the Doctrine of Proportion, contained in the 5th Book. It were likewise to be wished, that the young Student of *Astronomy* were skill'd in plain and spherical *Trigonometry*. But if there be any, as I believe there are some, who desire to learn *Astronomy*, and yet are ignorant of *Trigonometry*; I require of them, that they grant and allow us this Postulate; because in every *Triangle*, either spherical or plain, there are three Angles and three Sides; of these six, having any three, one of which in a plane Triangle must be a Side, all the rest may be found. It is *Trigonometry* that teaches us how to perform this, whose Use is apparent in all the Parts of *Astronomy*.

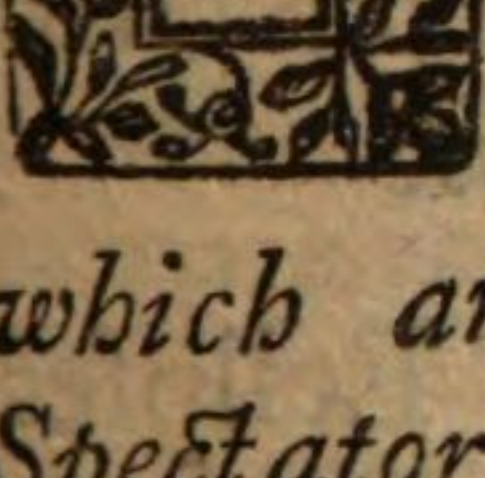
T H E R E are also some Things in our *Astronomy*, which require a Knowledge of deep *Geometry*, as when we speak of the Elliptick Theories of the Planets discover'd by *Kepler*. But I would not have the Beginners or young Students trouble themselves with these Particulars, so they may pass them over.

I desire also of them that are unacquainted with *Astronomy*, that after they have read the XI. and XII. *Lectures*, concerning the general Causes of Eclipses, they would leave the rest of that Doctrine, till they are instructed in the spherical Institutions, as they are explained by us in the XX. and XXI. *Lectures*; and then they may return to the remaining Parts of the Doctrine of Eclipses, contained in the XIII. and XIV. *Lectures*.

T H E Y who understand what is here deliver'd, may with much Advantage undertake to read that excellent Work of Dr. *Gregory's*, and learn the physical Causes of the celestial Motions from thence.



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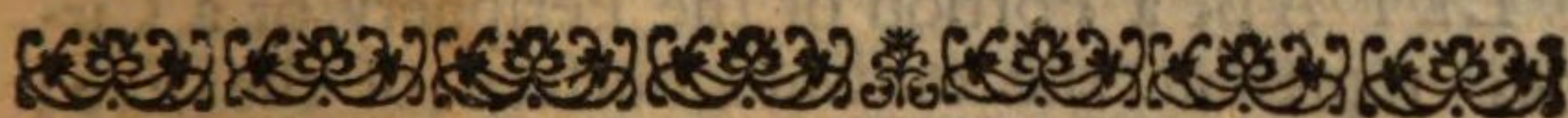
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ASTRO-



ASTRONOMICAL LECTURES.



LECTURE I.

Of Visible and Apparent Motion.



ASTRONOMY being a Sci-^{Lect. I.}
ence in which are explained the
Motions of Bodies that are at an
immense Distance from us, and
the Appearances which arise from
these Motions: They who would
learn this Science, must first be
informed of the Manner how the Motions of di-
stant Bodies become visible, and the Objects of
our Senses.

AND first it is plain, that since the Eye looks ^{What Bodies}
upon such Bodies to be at Rest, which keep the ^{seem to be at}
same visible Distance, the same Position and Si- ^{Rest.}
tuation, not only in respect of other Bodies which
we conceive to be at Rest, but also in respect of
the Eye that beholds them; those Bodies can only
B be

Lect. I. be perceiv'd to move, which change their Distances
 and Positions, in respect to other Bodies, or to the
 Eye of the Spectator.

*What in
 Motion.*

*Of the Sense
 of Seeing.*

Plate I.
 Fig. 1.

BUT that we may explain this Matter by its proper Principles, and draw it from its Origin, that is, from an Explanation of the Manner of Vision: It must be known, that the Writers of *Opticks* demonstrate that every Body which is seen, has its Image painted in the Bottom of the Eye, upon that Coat which is called Reticular, or the *Retina*, whose Surface is Spherical concave. This Image is made by the Rays of Light which flow from the visible Object to the Eye, and are therein received and refracted. The Image of each Point is in that Place, where the innumerable Rays which come from that Point, and passing through the Humours of the Eye, do by Refraction meet on the *Retina*.

LET AB, a Portion of the Periphery of a Circle, represent the outward Surface of the Eye; DG the Bottom or reticular Coat, which is formed by the Extremities of the Optick Nerves, and let C be the Center of the Eye; the Image of the Point F will be in the Line FCH, and therefore at H: So also the Image of the Point E will be in the Line ECL, at the Point L; for the Rays of Light will, by the pellucid and clear Coats and Humours of the Eye, be so refracted, that all those Rays which come from F, and enter the Eye, will change their Direction, and turn towards H, where they will meet; and likewise all those which come from E, being refracted in the Eye, will converge and meet again at L, where they will form the Image of the Point E; for by striking on the nervous Fibres in these Points, they will excite the Sense of Vision.

THERE is a fine Experiment which confirms and demonstrates this Doctrine. For if the Eye of an Ox, or any other Creature, just after its Death, be taken out of its Head, and the opaque and black Coat call'd the *Choroides*, which covers the back Part of the Eye, be separated, so that the thin and pellucid reticular Coat may appear; if
 this

this Eye be turned towards a Window, or any Object that is strongly illuminated, we shall see with Pleasure and Admiration, a fine Picture on the *Retina*, exactly representing the Object in its proper Colours. We shall have the same Appearance, if instead of the Eye we take any Convex-glass of a Telescope, and turn it towards the Object, and place a white Paper at a due Distance behind the Glass, we shall observe upon the Paper, an exact Image of the Object, distinctly represented with its lively Colours.

IF therefore the Image H of the Point F remain unmoved on the same Point of the *Retina*, the Eye being likewise unmoved, the Object F will be at Rest: But if the Point F be carried to E, its Image will thereby successively pass through different Parts of the *Retina*, and describing the Space H L, will excite the Sensation of Motion. If the Point F be at a great Distance from us, and the Motion be made in a Plane, passing thro' the Eye, the Spectator will judge of the Magnitude of the apparent Motion, by the Magnitude of the Angle F C E.

IF in the Line C F there be another Object M, which is likewise at a great Distance from us, and this Object be carried from M to N, its Motion will appear to be the same with that of the Object F; for the Way of both will appear the same, the two Images having the same Path, and passing through the same Space in the Bottom of the Eye. If the visible Point M be carried in the Line C F from M to F, such a Motion cannot be perceiv'd by the Spectator, the Image of M remaining unmoved all the while on the *Retina*: And whatever Bodies are moved in Lines that pass thro' the Center of the Eye, the Motions of such Bodies are not to be observed by our Sight, nor can we any other Way discern such Motions, but by the Increase or Diminution of the Splendor and visible Magnitude of the Objects. I speak here of distant Objects: For those that are near us, tho' they move in Lines passing thro' the Eye, yet we may discern

*How Motion
is perceived
by our Eyes.*

Lect. I. their Motions by the Change of Position and Situation which they hold in respect to other Bodies, whose Positions and Distances are known. Now whatever be the Path of the moveable Point F in the Plane FCE, whether it be in the right Line FE, or in the circular Arch FPE, or in any other curve Line FQE; when it comes to the Line CE, its apparent Motion will always be seen to be the same, while the Angle FCE remains the same; but when the Angle FCE is increased or diminished, the visible Motion will be in like Manner increased or diminished, which therefore can be only measured by that Angle.

THAT therefore the apparent Motions of Bodies may be determined, we must here shew the Method by which *Geometers* and *Astronomers* find out the Measures of Angles; which though it is commonly known, even to the meanest Artists, yet that we may omit nothing which will make what is to follow easily conceived by Beginners, we will here explain it in a few Words.

The Measures of Angles.

A Degree what.
Scruples or Minutes.

EUCLID has demonstrated, that the Angles at the Center of any Circle are proportional to the Arches on which they stand, and therefore the Measures of Angles will be best known from those Peripheries or Arches which subtend them: On which Account the *Astronomers* divide the whole Periphery of a Circle into 360 Parts, which are called Degrees; and they divide each Degree into 60 other Parts, which are named Scruples, or First Minutes; each of those Minutes are again divided into 60 second Scruples or Minutes; and each Second is also supposed to be divided into Thirds, each Third into Fourths; and so on.

By this Means they reckon no more Degrees or Parts in the greatest Circle than in the least that is; and therefore if the same Angle at the Center be subtended by two concentrical Arches, they count as many Degrees or Parts in the one as they do in the other; for these two Arches have the same Proportion to their whole Peripheries. For Example: Let ACB be an Angle, and from the Center

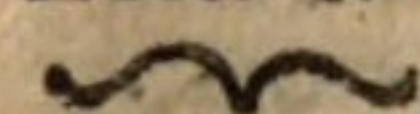
Plate I.
Fig. 2.

Center C let there be described two Arches AB, DE, subtending the Angle: There are as many Degrees and Minutes contain'd in the Arch AB, as there are in the Arch DE, altho' the Radius or Semidiameter of the Arch AB were only a Foot long, and the Radius of the other reached the Fixed Stars. It is true indeed, that a Degree in the Arch AB is so much less than a Degree of the Arch DE, as its Radius CB is less than CE or CD: The Angle C is said to be of so many Degrees or Minutes as the Arch which subtends it contains of such Parts.

THE Instrument by which Angles are observed, is a known Portion of the Periphery of a Circle, as a Quadrant, Sextant, or Octant, that is, the fourth Part, sixth Part, or eighth Part of the whole Periphery. If it be a Quadrant, the Instrument-Makers divide it into 90 Degrees, 90 being the $\frac{1}{4}$ th of 360: If a Sextant, it is divided into 60, which is the $\frac{1}{6}$ th of 360: If an Octant, it contains 45 Degrees, or the $\frac{1}{8}$ th of 360. They divide again each Degree into Minutes, and each Minute into Seconds, if the Instrument be large enough to shew such Parts. The Instrument-Makers fix to the Side of the Instrument Pins or Sights, by which they collineate to the Object, and they fasten likewise a Rule moveable about the Center upon the Plane of the Instrument, which Rule is likewise furnished with Sights, with which they observe Angles in this Manner.

LET A and B be two Objects at a great Distance from us: And suppose the Observer at C, who is to measure the Angle ACB: Let the Instrument be turn'd, 'till the Object A can be seen thro' the Sights of the Side CD; and let the Plane of the Instrument be so moved round the Side CD, and the Rule round the Center, that the Object B may be seen thro' the Sights of the Rule: It is manifest from what has been said, that the Arch DE will give the Measure of the Angle ACB, and that the Arch AB will contain as many Degrees and Parts, as the Arch DE, which the Rule cuts off from the Instrument.

Lect. I.



The Hori-
zon.

The Alti-
tude of a
Star.

The Pole of
the Horizon.

MOREOVER *Astronomers* have other Bounds or Marks from which they reckon the *Arcual* Distances of Stars, and measure them with a like Instrument. These are chiefly the *Horizon*, which is formed by a Plane touching the Surface of the Earth where the Spectator stands, and is infinitely extended towards the Heavens; which it divides into two Hemispheres, or Parts sensibly equal, and separates the Visible Heavens from the Invisible. And if we suppose a Circle perpendicular to this Horizon passing through any Star, the Arch of it comprehended between the Star and the Horizon, is called the Altitude or Height of that Star. There is another Mark which is called the Pole of the Horizon, and is that Point which is directly overhead, through which a Line perpendicular to the Horizon will pass: And it is in this Line all heavy Bodies endeavour to descend, and according to which we stand upright. By this Method the Sailors at Sea find out the Height of the Sun by the Angle which is formed in the Eye, by Lines coming from the Sun, and from the Horizon. So likewise the *Astronomers* by Rules and Quadrants made on Purpose for that Use, observe the Angle which the Rays or Lines that come from the Sun or Stars, make with the Line that is perpendicular to the Horizon.

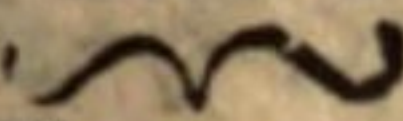
INSTEAD of plain Sights we now commonly make Use of *Telescopes*; for by their Means distant Objects are more certainly and exactly observed, than they can be by our simple View. The Manner of fitting *Telescopes* to Instruments, the Method of dividing the Arch, and the Contrivances for managing and moving the Instrument for Practice, we leave to the *Mathematical* Instrument-Makers to describe.

Plate I.

Fig. 4.

The appa-
rent Diame-
ters of Bo-
dies.

By the Measure of Angles we likewise find the apparent Diameters of distant Bodies: Let AB be a Line which is seen by the Eye at C directly opposite to it, and suppose drawn from its Extremities A, B , right Lines AC, BC to the Eye; that Line AB is said to appear under the Angle ACB ,

ACB , which is call'd its apparent Magnitude, Lect. I. and is said to be so many Degrees and Minutes as  that Angle observed by an Instrument contains. After the same Way the Object DE , seen by the Eye F , is said to appear under the Angle DFE , and the apparent Magnitudes of the Lines AB , DE , are to one another, as the respective Angles ACB , DFE . Fig. 5.

BUT if the Eye come nearer to the Object AB , so as to view it but from half the Distance, that is, from G ; the Object will be from thence seen under twice the Angle it appeared under before: If the Eye come three times nearer, its apparent Magnitude will be near three times greater, provided the Angles be but small, and exceed not a Degree or two: And the apparent Diameters of such Objects do nearly increase, as the Distances from which they are view'd are diminished. *The apparent Diameters, the nearer we approach them, grow bigger.* Fig. 4.

By this Method, if we know the apparent Diameters of two Bodies, and the Proportion of their Distances from us, we can know from thence the Proportion their true Diameters bear to one another: For if their Distances be equal, their true Diameters will be as their apparent. And if their apparent Diameters are equal, their true Diameters will be proportional to their Distances. For Example: If the Angle ACB be equal to the Angle DEF , but the Distance CB triple of the Distance EF , the Line AB will be triple of the Line DE : But if the Distance CB be not only triple of the Distance ef , but also the Angle ACB be double of the Angle dfe , the Object AB will be sextuple of the Object de : For if we suppose CM equal to df , and an Object MN to appear under the Angle MCN or ACB ; because the Angle MCN is double of the Angle dfe , MN will be double of de ; but because CB is triple of CM or df , AB will be triple of MN , and consequently it will be six times bigger than de . Hence, if the apparent Diameters of the Sun and Moon be equal, let the Sun be 100 times further from us than the Moon, the Sun must needs be 100 times in Diameter bigger than the Moon: We shall afterwards demonstrate,

Lect. I. that the Sun's Distance from us is above 100 times greater than that of the *Moon*.

IF we know the apparent Diameter of any Body, we can from thence exactly know, by the Help of *Trigonometrical* Tables, what Proportion the Distance of that Body bears to its true Diameter. For suppose the Object DE to be seen by the Eye at F under the Angle DFE. For Example of one Degree; then the Distance FE will be to DE the Diameter of the Object, as the Radius of a Circle is to the Tangent of the Angle DFE; that is, supposing DFE one Degree, as 10000 is to 174.5. The Sun appearing under an Angle of about half a Degree, or 30 Minutes, its Distance will be to its own Diameter as 10000 to 87: Hence, we are certain that the Sun's Distance from us, is nearly equal to 115 of its own Diameters. And if an Eye were placed in the Sun, to observe the Angle under which the Diameter of the Earth appeared from thence, we then should be able to tell exactly the Distance of the Sun from us, in Diameters of the Earth, or in Miles.

*The Advan-
tages of Te-
lescopes.*

SINCE, as we have said, the apparent Diameters of Bodies grow bigger, the nearer we come to them, and that they are increased almost in the same Proportion that the Eye approaches them; (for Example: If any Man were ten times nearer to the Moon than we are, and did there observe it, he would see the Moon ten times bigger in its Diameter and clearer than we do; in Diameter I say, for the Surface would appear 100 times larger than it does to us:) If here on Earth we should take a Telescope which only increases the Diameter ten times, and look to the Moon with it, the Moon will have the same Appearance seen with such a Telescope, as would appear to a Spectator ten times nearer it than we are. But if we should use Telescopes (and such there are) which magnify the Diameters of Objects 100 or 200 times, they will shew the Moon in the same Manner, Figure and Bigness, as it would appear in, at a Distance 100 or 200 times less than ours.
Hence

Hence we can perceive with our Eyes with what Face, and how large the Moon would shew itself, at the Distance of three Diameters of the Earth: As likewise we can discern how it would appear, if we approached it much nearer, and view it only at the Distance of 1000 Miles; for from thence we should be able to discover in it vast Ridges of Mountains, deep Caverns, many Vales, and large open Fields. By the Means of Telescopes we still ascend higher in the Heavens, and we can approach the Planets, Comets and fixt Stars so near, that of such immense Distances there remains only the hundredth, or two hundredth Part to have the whole Journey finished; and from thence we can behold the Conversions of the Planets about their proper *Axes*; the Moons of *Jupiter* and *Saturn*, their Eclipses; the Belts of *Jupiter*, the wonderful Ring of *Saturn*, and all the various Appearances and Shapes it takes. We could not pass over, without taking Notice in this Place, these Advantages of the Telescope, since it is the chief Instrument by which we observe the Magnitudes of the heavenly Bodies, and their apparent Motions.

SINCE the Motions of distant Bodies are no other ways to be known, but by the Change of the Angle which is at the Eye that observes them; it will easily appear from thence, that tho' Bodies move equally and regularly, describing equal Spaces in equal Times, their Motions notwithstanding may seem to be very unequal and irregular. This will be best understood by an Example.

SUPPOSE a Body to be revolv'd in the Periphery of a Circle *ABDEFGQ*, and to move thro' equal Arches *AB*, *BD*, *DE*, *EF*, in equal Times; and let the Eye be in the Plane of the same Circle, but at a Distance from it, viewing the Motion of the Body from *O*: When the Body goes from *A* to *B*, its apparent Motion is measur'd by the Angle *AOB*, or the Arch *HL*, which it will seem to describe; but in an equal Time, while it moves thro' the Arch *BD*, its apparent Motion is deter-

*How the
Motions of
far distant
Bodies,
which are
in themselves
equal, may
appear un-
equal.*

Plate I.
Fig. 6.

Lect. I.  determined by the Angle B O D, or the Arch L M, which is much less than the former Arch H L; and the Body, when it arrives at D, will be seen at the Point M of the Periphery N L M: But it takes the same Time to describe D E which is equal to A B, or B D; and when it arrives at E, it is still seen at the Point M; so that all the Time it is moving thro' the Arch D E, it appears almost immoveable, and, as it were, to stand still. While the Body is continually going forward in its proper Orbit, and describing the Arch E F, when it comes to F, the Eye in O will see it in L, and it will appear to have gone backwards in the Arch M L. So also, while it moves from F to G, at its Arrival at G, it will be seen at H in the very same Place it appeared in when it was in A. So likewise, while it passes from G thro' I to Q, the Spectator's Eye at O will observe it, as if it had describ'd the Arch H K N. And tho' it is still going on in its Orbit, while it runs thro' the Arch Q P, the Spectator will observe it all that Time near the Point N, in a *Stationary* State. After its passing by P, and going to A, it will appear to change again its Course, and describe the Arch N K H with very unequal Motions.

Optical Inequality.

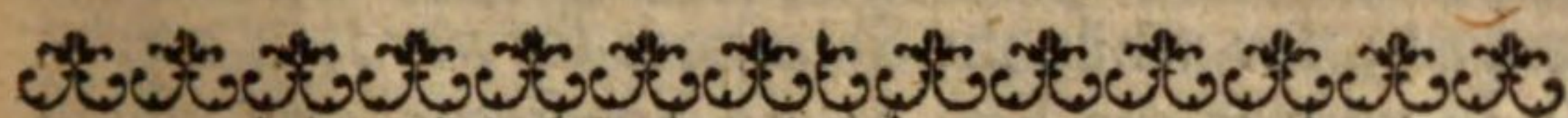
THIS Inequality of Motion is call'd by *Astronomers* the *Optical Inequality*: Because it is not really in the Bodies moved, but only apparent to the Eye which perceives it, arising from the Position of the Spectator: For the Body all the Time moves uniformly forward, and if the Eye were in the Center, it would see the Motion always perfectly regularly performed.

Plate I.
Fig. 7.
If the Eye be placed within the Circle, the Motion that is equal, may appear unequal, but the Body can never be seen to go backward, or to change its Course,

IF the Eye were placed in any Point, as O, within the Orbit of the Body, but not in the Center, and there the Spectator remained immoveable, he would still observe the Motions to be unequal, altho' the Body moved never so regularly; and when at the greatest Distance from him, as at A, it would appear to be slowest; when it comes nearest, it would seem to move quickest. This is plain; for the Arches A B and C D being equal, they

they will be described in equal Times. But the Angle DOC being greater than AOB , the Motion in D will appear swifter than that at A . But in this Case the Body will never appear to stand, or to go backwards, but always forward: And therefore, when a Spectator placed within the Orbit of another Body, and viewing its Motion, perceives it sometimes to go forward, then to stand still, and afterwards go backward, we may from thence conclude, that the Place of the Spectator is likewise moved.

Lect. I.



LECTURE II.

Of the Apparent Motion which arises from the Motion of the Spectator or Observer.



HERETO we have supposed the Spectator to have remained immovable all the Time of the Observation: But if the Place of the Observer be likewise moveable, then there will be very different Appearances, and the Eye will perceive those Bodies to be at Rest which may have really a very quick Motion; and other Bodies may seem to be in Motion, which remain really at Rest: And not only these Appearances may be seen, but the Motion of Bodies may appear to be directly contrary to what they truly are; and Bodies which are really going *Eastward*, may appear to move towards the *West*. All which will be most easily declared and made plain from the Appearances observed by them who sail in a Ship.

SUPPOSE a Ship carried by the Winds with a swift, but uniform Motion; the Passengers can neither perceive the Motion in the Ship, nor of

They who sail in a Ship, perceive not the Motion of any the Ship.

Lect. II. any thing in it that keeps the same relative Place in the Ship: For since the Vessel and all its Parts retain the same Situation and Position in respect of the Eye, their Images painted on the *Retina* will always abide in the same Place, and therefore they must appear unmoved. Hence it is, that tho' every thing in the Ship goes as fast forward as the Ship itself does; yet such Motions cannot be perceived by a Spectator that sits in the same relative Place, and who has the same common Motion with the Ship. But when the Spectator turns his Eyes towards the Shore, or upon Objects which are without the Ship, they will seem to be moved; for while the Ship goes forward, it carries along with it the Eye of the Spectator, by which Motion of the Eye the Position of external Objects in respect of itself will be changed, and their Images will successively occupy different Places on the *Retina*; and therefore Objects without the Ship, which are really at Rest, will seem to be moved, whereas those that are within the Ship, and really in Motion, will appear to be at Rest.

But external Objects without the Ship will seem to move.

The Motion of a Ball falling down in a Ship.

IF, while the Ship is moving very fast forward, a Ball of Lead, or any other heavy Metal, were let fall from the Top-mast, the Passengers in the Ship will observe the Ball to fall perpendicularly downwards, and it will fall upon the Deck just by the Foot of the Mast, after the same Manner as it would fall were the Ship at Rest. But notwithstanding this, the true Motion of the Ball is not in the Perpendicular, but in an Oblique Line, in which it descends; and a Spectator in another Ship which is at Anchor, will easily observe this Obliquity and Curvity of its Way, while it falls thro' the Air. The Reason of this Appearance is easily shew'd: For according to the first and principal Law of *Natural Philosophy*, a Body once put into Motion, endeavours to retain that Motion, and to continue moving in the same Direction. Now the Ball, while it was held at the Top-mast, went forward with the Ship, and had its Motion communicated to

to it; and therefore, after it is left to fall, it will retain the same Force to go forward as it did before; and at the same Time, its Weight carrying it downwards, it will both go forward and descend: For the two Forces, one communicated by the Ship, and the other from Gravity, will not hinder or diminish one another, they not being contrary. It will therefore be moved as fast forward, and as much downward, as it would be, did the two Forces act upon it separately at different Times. By these two Forces acting together, the Rectitude of its Way is only hindered; which it would have, did the Perpendicular and the *Horizontal* Forces act separately; and the real Way of the Ball thro' the Air is a curve Line, exactly like that which a Body takes when it is thrown according to an *horizontal* Direction: And in such a Line it will be observed to move, by a Spectator placed near it in another Ship which is at Rest. Besides, since the Ball and Mast are both moved forward with the same Velocity, they will always remain at the same Distance from each other; and therefore the Ball will touch the Deck just by the Foot of the Mast. Moreover the Motion of the Ball forward is common to the Ship, and all its Parts, as likewise to the Passengers that are relatively at Rest in the Ship. But we have before shewed, that the common Motion could not be observed by the Passengers in the Ship, and therefore it cannot be perceived neither while the Ball is falling. Wherefore the only Motion that can be seen, will be that which is imprest upon it by its Gravity, which is peculiar to the Ball, and by which it descends. And therefore the Passengers will see the Ball descending only in a perpendicular Line. Experiments have been often made, which demonstrate that all we have said is exactly true.

If any Person sitting at the Ship's Head, should throw a Ball towards the Stern with the same Velocity that the Ship goes forward, that Ball would neither go forward nor backward; and if there were no Gravity, it would remain immoveable:

But

*The Motion
of a Ball
thrown
within the
Ship.*

Lect. II. But because Gravity acts upon it, it will really descend in a perpendicular Line, and a Spectator in a Ship at Anchor would observe it descending in a Right Line. For the Force imprest upon it when it is thrown, will only destroy the first Force communicated to it from the Ship, to which the projectile Force is contrary and equal. But for all this, the Passengers will not perceive this perpendicular and direct Motion; but they will see the Ball go towards the Stern with the same Force, as it really would have done, had the Ship been at Rest, and the Ball been thrown with the same Force to the Stern.

BUT if the Velocity with which the Ball is thrown toward the Stern should be less than that of the Ship, the real Motion of the Globe will be forward, in the same Direction in which the Ship goes, but slower than it; for the whole Motion communicated by the Ship will not be destroy'd, and there will still remain a Part of its former Motion, by which it will be carried forward, tho' not so fast as before. But the Passengers will perceive no such Motion, but they will observe the Ball to be moved in a Line directly contrary to its real Motion, with that very Velocity that it would have, were it thrown when the Ship is at Rest: Hence it is plain, that Bodies may appear to have a Motion directly contrary to their real and absolute Motion.

*In Objec-
tion.*

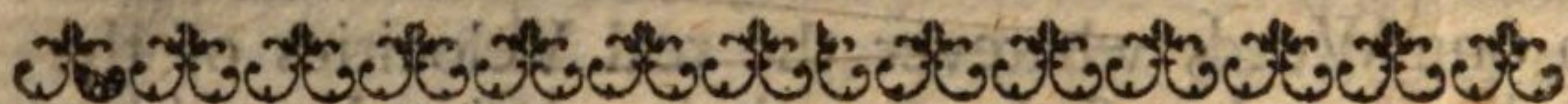
BUT some may object, that the Ball thus thrown, will really hit the Stern of the Ship, and impress on it a considerable Blow, which it could not do, had it not a Motion towards the Stern. But this Difficulty is easily removed; for tho' they that are within the Ship see the Ball go and hit the Stern, a Spectator without, who is not in Motion, will observe that the Ball does not come upon the Stern, and give it a Stroke, but that the Stern rushes upon the Ball, and acts upon it with all its Force: And the Force of the Stroke which each Body receives, is the same as if the Ship had been at Rest, and the Ball had fallen upon it with
the

the same Velocity that the Stern does really come Lect. II.
against the Ball; for it is known from the Laws of Motion, that if there be any two Bodies, A and B, equal or unequal, the Force of the Stroke will be the same, whether B with a certain Degree of Velocity comes upon A, which is at Rest; or if B shall be at Rest, and A with the same Velocity rushes upon B; or if both Bodies move the same way, but A, moving faster by its greater Velocity, gives B an Impulse, the Force of the Stroke will be the same as if B were at Rest, and A came upon it with the Difference of their Velocities, that is, by the Excess wherewith the Velocity of A is greater than that of B: Or lastly, if A and B have contrary Motions, and hit one against the other, the Greatness of the Stroke will be the same as if one of them stood still, and the other came against it with the Sum of their Velocities. In one Word, whatever the real Velocities of the Bodies may be, so long as their relative Velocities, or the Velocities by which they approach each other, remain the same, the Force of the Stroke will likewise remain the same. Hence it is, that in a Ship, however swiftly it may sail, all our apparent Motions, and the Motions of every Thing in the Ship, do all appear to be the same that they would, were the Ship at Rest: And it is observable, that *Flies* and other *Insects* keep the same Motion in regard to one another, whether the Ship is at Rest, or sails uniformly forward with any Degree of Velocity, let it be never so great. And it is universally true, that all Bodies that are shut up in any one Place, preserve the same Motions in regard of one another, and all Appearances will be the same, whether the Place remains unmoveable, or has a direct uniform Motion forward.

I HAVE brought these Examples, that you may perceive how wide the Differences may be between real and apparent Motions, and how hard it is to judge of real Motions, by those that are seen.

BY

Lect. II. By this it is evident, that if a Spectator were placed in *Jupiter*, or *Saturn*, or any other of the *Planets*, he can never be made sensible of the Motion of his own Habitation, no more than they who sail in a Ship can perceive the uniform Motion of the Ship. Passengers who sail in Ships may indeed be very sensible of the frequent Tossings and sudden Shocks the Ship receives from the Waves and Wind, which they find exceedingly troublesome to them. But the *Planets*, which compose a Celestial Fleet, are not liable to any Storm; they without any Disturbance or Commotion circulate in their Orbits, and sail, as it were, in a most pacifick Ocean, which is continually calm and serene.



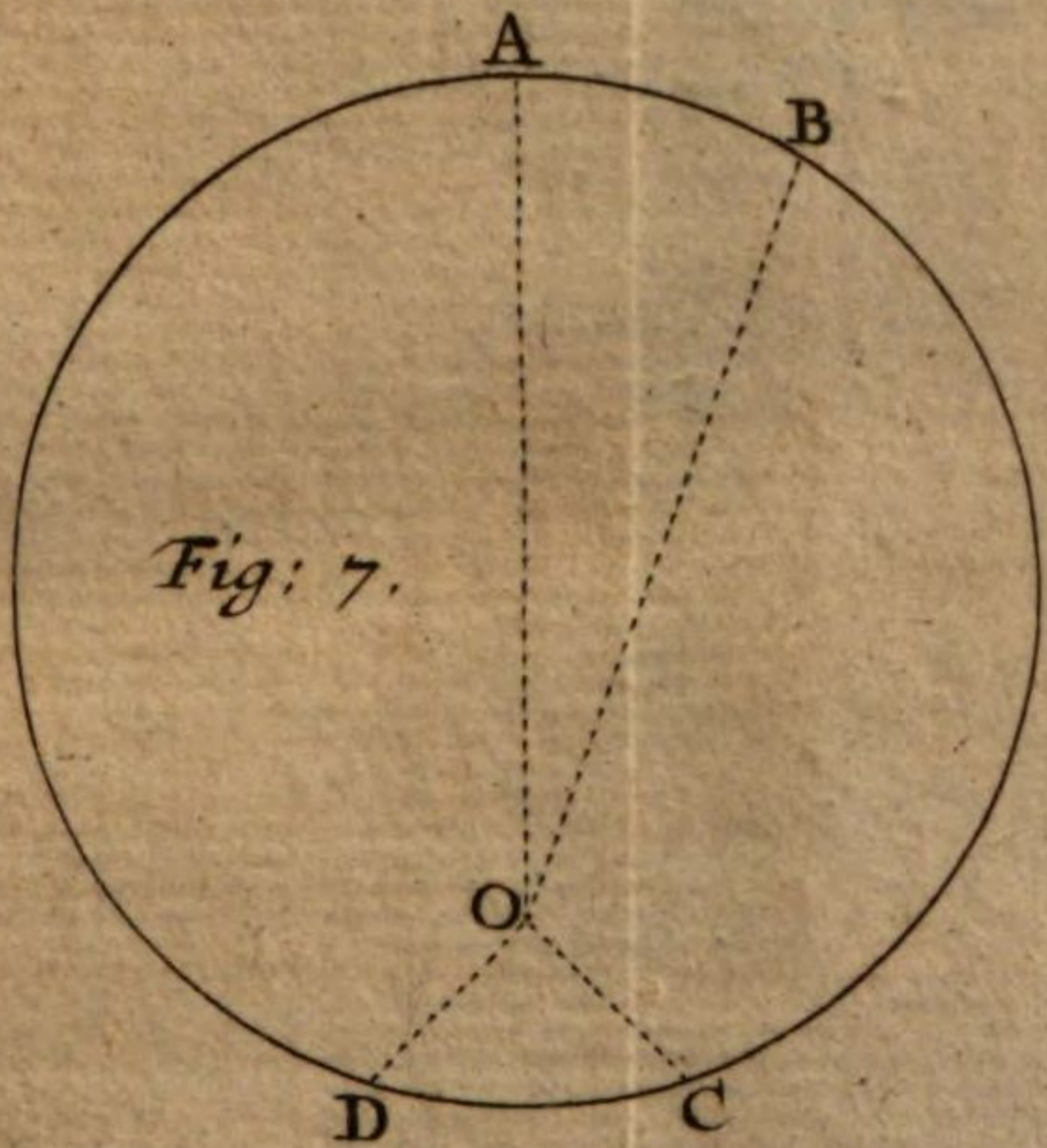
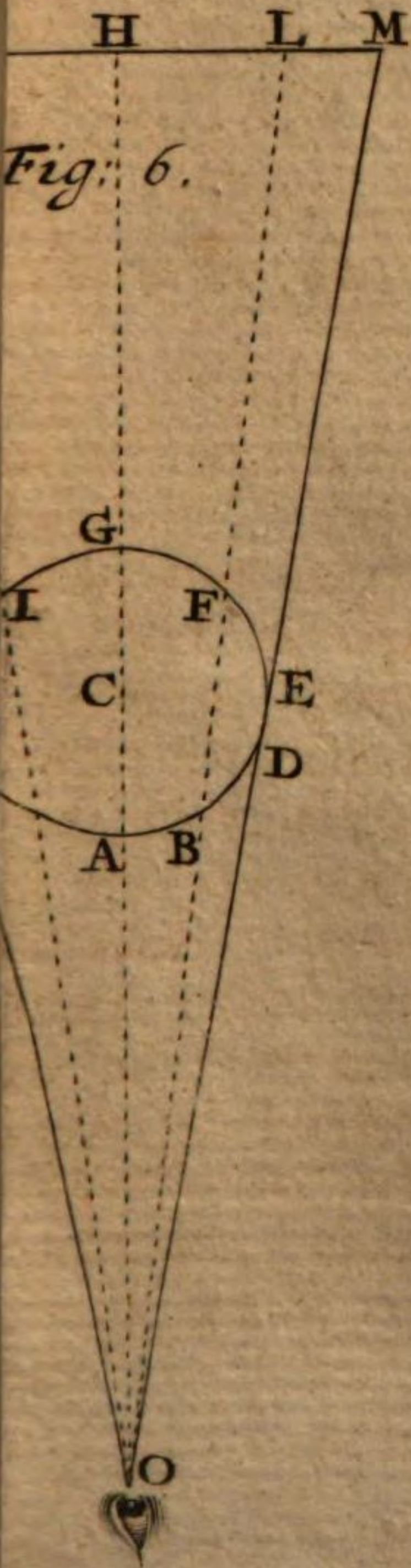
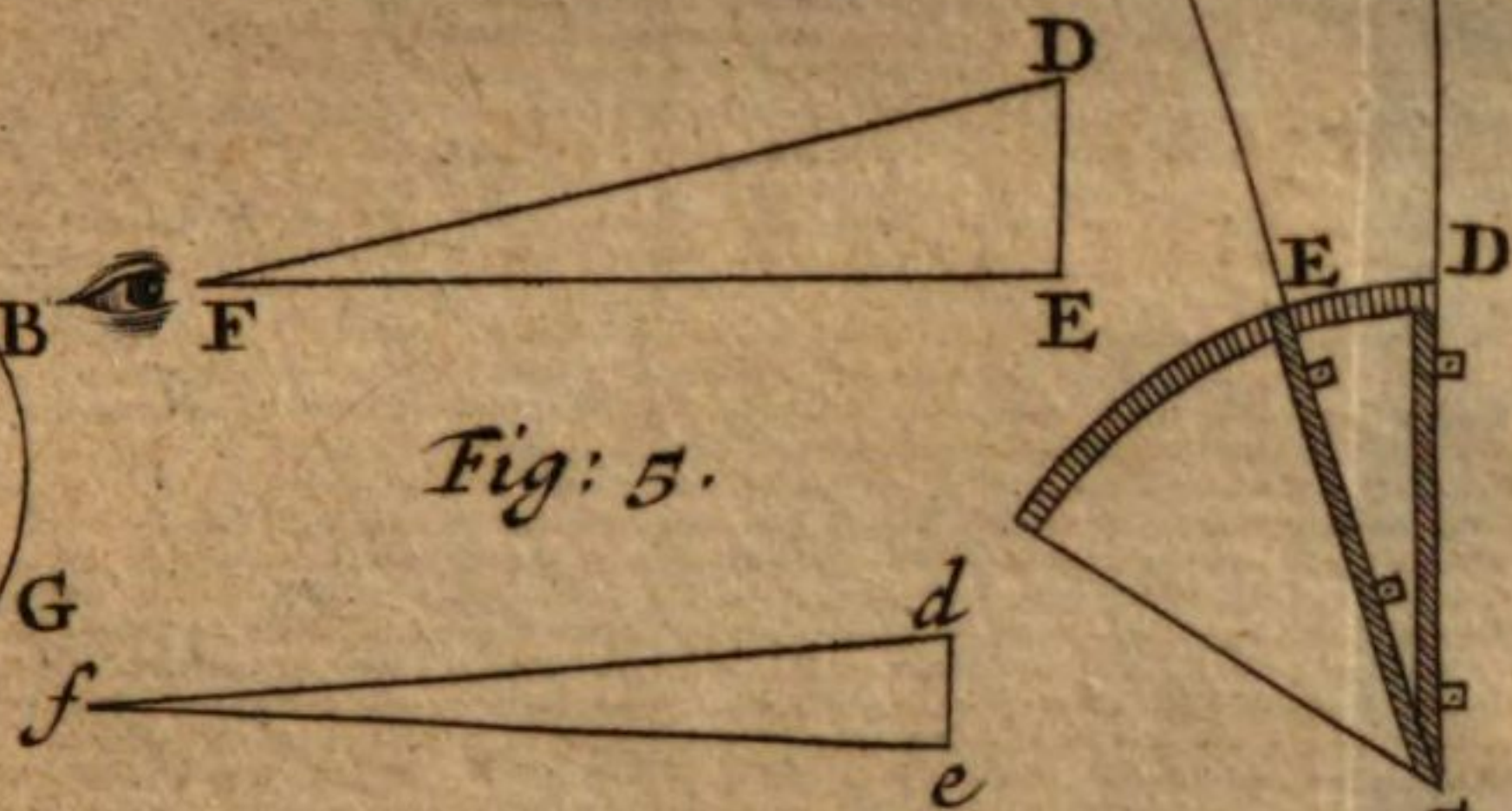
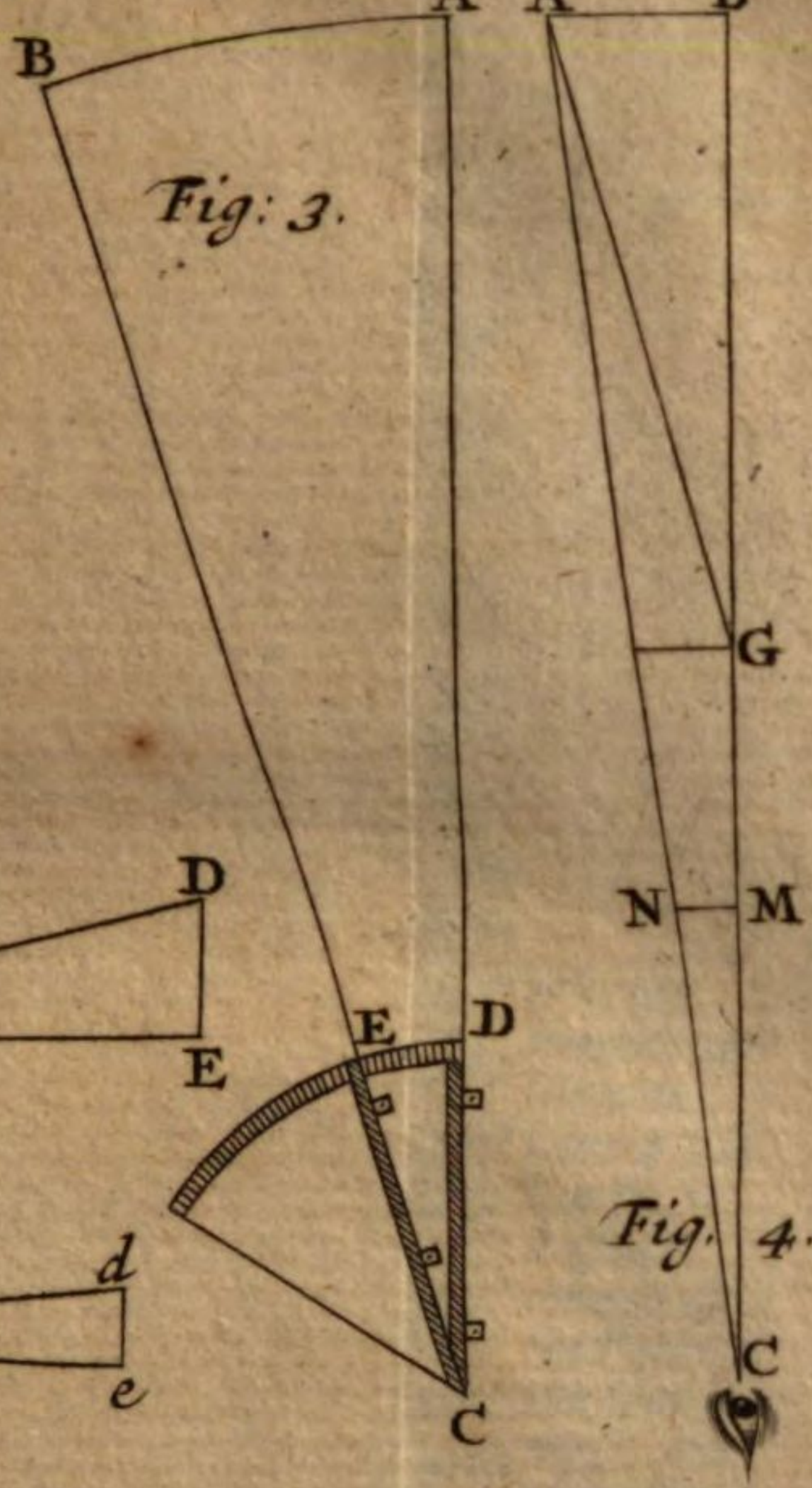
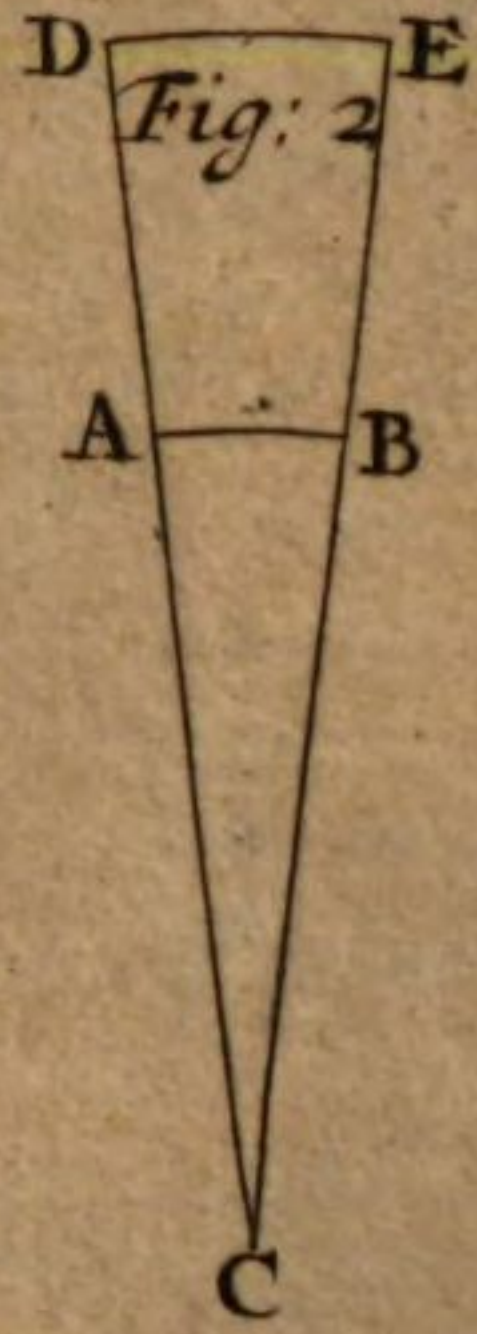
LECTURE III.

Of the System of the World.



WE have shewed, that according to the different Situation and Motions of the Spectator, the Appearances of Things will be very various and different. That we may have a more distinct Knowledge of the Fabrick of the *World*, and that the admirable Beauty of the Universe, and the harmonious Motions of the Bodies therein contained, may be more easily understood, it will be requisite, that that divine and immense Fabrick should not be observed from one Point or Corner only: But as in viewing of large Palaces, we take the different Prospects they afford from several Places; so here, to have a true and just Notion of the World, we must suppose it to be observed in different

Plate I.



different Situations and Distances, that by con- Lect. III.
templating the various Prospects it gives us, and
comparing them together, we may obtain at last a
distinct Knowledge of this immense Palace of God
Almighty, and have an *Idea* or Image of it im-
pressed on our Minds, which is worthy of its In-
finitely wise *Architect*.

IN order to understand therefore the Heavenly
Bodies, their Motions, and Appearances, which are
called *Phænomena*, we must feign ourselves not
to be Inhabitants of this *Earth*, and fixed to one
Habitation, but suppose we have the Power of
Travelling every-where, thro' the immense Re-
gions of indefinite Space: And therefore we will
sometimes take Possession of some immoveable
Place; from thence we will transfer ourselves to
the *Sun*, to observe the Regularity and Harmony
of the Motions which are to be seen from thence;
afterwards we will take a Journey to some other
of the *Planets*, that we may from them observe
the apparent Motions of the Heavens; nor will
we confine ourselves within this *Planetary*
System, but we will ascend much higher in the
Heavens, and view the World from a *Comet* or
fix'd *Star*.

*We may imagine our-
selves to have a free
Course, or
Passage,
through all
the Parts of
the Uni-
verse, and
of passing
from one
Star to an-
other.*

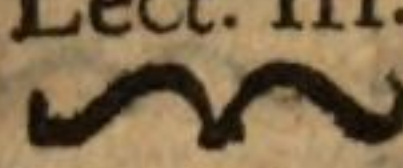
*We, tho' from Heav'n remote, to Heav'n will move
With Strength of Mind, and tread th' Abyss above:
And penetrate, with an interior Light,
Those upper Depths, which Nature hid from Sight.
Pleas'd we will be to walk along the Sphere
Of shining Stars, and travel with the Year.
To leave this heavy Earth, and scale the Height
Of Atlas, who supports the Heav'nly Weight:
To look from upper Light, and thence survey
Mistaken Mortals wand'ring from the Way.*

OVID's *Metamorphosis*, Book XV.

C

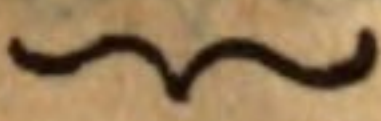
Now

Lect. III. Now, tho' our Bodies, by reason of their

 Gravity towards the Earth, are detained, as it were, Prisoners in this earthly Mansion; yet nothing hinders, but that, with our Mind and Imagination, we may wander thro' all the Heavenly Regions, and from them contemplate, with the Eyes of our Reason, the whole System of *Nature*. Nor do I see how this Liberty of Imagination can be denied us, which was always allowed to the *Astronomers* of all Ages; for they, to observe the equal Motions of the Heavens, thrust the Spectator down to the Center of the Earth, and supposed that the Heavens were viewed from thence, as from the Center of a crystal *Globe*. An *Astronomer* thinks it no great Concession or *Postulatum*, that he can draw a Line from the *Sun* to the Center of the Earth; and from thence again to any *Planet* or Star. He divides the Heavens with his Circles, and marks out the Ways of the Planets; and indeed without such a Licence he could never have brought *Astronomy* to any Degree of Perfection.

As therefore it was a Custom among the *Astronomers*, to place the Eye in the Center of the Earth, to view from thence the apparent diurnal Revolution of the Heavens; which would from thence be seen an equable Motion: We will on the contrary, carry the Spectator to some immoveable Place in the Heavens; that the real and absolute Motions may be observed from thence, as much as they can be, equable and uniform. For the *Astronomers* of all Sects do agree, that the Motions of the Planets are in themselves simple, regular, and uniform: But when the Heavens are viewed from the Surface of the Earth, or even from its Center, the Planets seem to be carried by very unequal Motions, and not to observe any regular Course; and therefore we may certainly conclude, that our Earth is not placed in the Center of their Motions. He therefore that would observe the real and proper Motions of these Celestial Globes, must first place himself

*The Planets
seen from the
Earth, have
unequal, and
irregular
Motions,*

himself in the Center of the Sun, or in some Lect. III. Point or Space not far distant from it; and then  let him consider what will be the Appearances or *Phænomena* he will behold from thence.

AND, first, it is to be noted, that where-ever *The Specta-* the Spectator resides, he will still be in the Cen-^{tor is al-} ter of his own View; for in an indefinite Space,^{ways in the} where there is nothing to bound our Prospect,^{Center of} all Objects that are at a great Distance from us,^{his own} tho' they be at immense Distances from one an-^{View.} other, yet, if they appear in the same right Line which passes through the Eye, will be seen at the same Point of Space; and all Bodies will appear equally remote, when their Distances from us become so great, that the Eye cannot estimate or judge of them: And consequently the Spectator will look upon them all as placed in the Surface of a Sphere, which has the Eye for its Center, and whose Surface is at an immense Distance, in which Surface all the heavenly Bodies will seem to perform their Motions. Thus, tho' the *Moon* be many Millions of Miles nearer to us than the *Sun*, and he again much nearer than the fixed *Stars*, yet all appear as placed in the same concave Surface of the Heavens: And even the Clouds, which are but a few Miles above us, would be judged to be as far distant as the *Moon* and *Sun*, if they did not sometimes cover them, and obscure their Light. In whatever Place therefore the Spectator resides, whether it be in the *Earth*, or the *Sun*, or in *Saturn*, the furthestmost of the *Planets*, or even in a fixed *Star*, that Place will be looked upon by its Inhabitants as the middle Point of the Universe, and the Center of the World; since it is the Center of that Spherical Surface in which all distant Bodies seem to be placed.

A Spectator therefore living in the *Sun*, when *The Pro-* he looks towards the Heavens, will observe its^{spect of the} Surface to be spherical-concave, and concen-^{World from} trical to his Eye; in which Surface he will ob-^{the Center of} serve an innumerable Multitude of *Stars*, which

Lect. III. we call *Fixed*, every-where dispersed throughout the whole Heavens, which, like so many gilded Studs, with a bright Lustre adorn the Firmament. These *Stars* we call *Fixed*, because, as seen from the *Earth*, they preserve the same immutable Positions and Distances from each other; and so from the *Sun* likewise, they will appear always to retain the same Situations in respect of one another, nearly as they are observed to have when seen from the *Earth*. For their Distance either from the *Earth* or *Sun* is so great, that the little Change of Place, (however great it be, when compared to our common Measures) which is made by bringing a Spectator from the *Earth* to the *Sun*, will scarcely make any Change in the visible Situation of the Stars. Now, tho' the fixed Stars seen from the *Earth* do always preserve the same Distances, Positions and Situations in respect of one another, yet in respect of the Eye we observe them to change their Positions, and sometimes they seem to mount higher in the Heavens, and to come more perpendicularly over us; then they descend again, and appear to turn round in Circles, some in greater, some in less, about an Axis which is the Axis of the *Earth*: And this Circumvolution of theirs is every Night to be observed from the *Earth*; but whoever would view them from the Center of the *Sun*, would perceive them absolutely immoveable, and always abiding in the same Place of the Firmament. And this Appearance will be the same, whether the Stars do really rest in the same Place; or whether the Heavens, in which the Stars are placed together with the *Sun*, revolved round the Axis of the *Earth*: For if there were really any such Revolution of the Heavens, a Spectator in the *Sun* would have that Motion in common with the Stars; and therefore he could be no more made sensible of it, than a Passenger in a Ship can observe by his Senses the Course and Motion of the Ship.

The immense Distance of the fixed Stars from the Sun.

The Stars change their Position in respect of the Spectator.

BESIDES the innumerable Stars at Rest, there are Six other shining Globes to be observed, which

which perform their Circulations round the Sun, Lect. III, in very different Periods of Time: And therefore, they must have constantly variable Positions, and be always changing their Distances from one another, as well as from the quiescent Stars. These Globes or Stars are called *Planets*, which signifies *Wanderers*, and one of them is the *Earth*, the Place of our Abode. And even tho' we should suppose the Earth to be at Rest, and that the Sun did really move round it in the Space of a Year, yet a Spectator in the Sun would observe, that the Earth turned round about him; and would see it describe the same Circle in the Heavens, that we in the Earth observe the Sun to perform his Course in; as we shall afterwards demonstrate.

THE Names and Characters, or Marks for the Planets are *Saturn* ♄, *Jupiter* ♃, *Mars* ♂, the *Earth* ⊕, *Venus* ♀, *Mercury* ☿. These Characters were invented by the *Astronomers*, as Abbreviations in Writing. The Planets do all turn the same Way as the Sun from the *West* to the *East*. The *Planets* in Orbits which lie in Planes, which are not much inclined to one another, but nearly coinciding: So that the Planes of these Orbits in the Heavens, being little inclined to one another, make Angles with that Circle in which the Earth is seen to turn round the Sun, but of a very few Degrees. As all Planes that are not parallel, cut one another in right Lines; so the Planes of the Orbits in which the Planets move, cut one another in Lines that pass through the Sun's Center; and therefore a Spectator there placed will be in the Plane of each Orbit, and will observe that the Planets moving in the concave Surface of the Heavens, perform their Motions in great Circles, which divide the Heavens into equal Portions. Now the Eye being, in this Situation, in the Planes of all the Planets Orbits, can never by that Means judge of their different Distances from the Sun; for from thence they will all seem to be at the same Distance from him: And therefore to observe their different Distances,

Lect. III. as well as Periods, it will be necessary that our Spectator should remove from the Sun, and rise above the Planes of all the Orbits, in a Line perpendicular to the Plane of the Earth's Orbit; and, for Example's sake, let us suppose him to rise so high, as that his Distance from the Sun may equal the Earth's Distance from it, and let him there make his *Astronomical* Observatory: From thence he will not only observe the same fixed Stars in the same Position as before, but he will see both Sun and Planets in the Heavens: The Sun indeed will appear like the fixed Stars, immovable; but the Planets will be seen to turn round in lesser Circles about him, at very different Distances, and in different Periods: They who finish their Circuits soonest, are seen nearest to the Sun, and the Circles they move in are the least; they who take a longer Time in revolving, describe larger Circles, and are further removed from the Sun; and the Order of the Planets will be such as is represented in Figure 1, Plate II. Where the Sun remains unmoved in the Center of all the Orbits; round about him six Planets make their Revolutions, viz. *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*, all from the West to the East, according to the Order of the Letters ABCD. *Mercury* is next the Sun, and finishes his Course in three Months: *Venus*, in an Orbit somewhat larger, performs her Period in eight Months: Beyond the Orb of *Venus*, is that of the *Earth*, which revolves round the Sun in the Space of a Year: *Mars* takes two Years to complete his Circulation: And *Jupiter*, at a much greater Distance, does not finish his Revolution till after twelve Years: The furthestmost and slowest of all is *Saturn*, whose Orbit includes all the others, and requires not much less than 30 Years to complete his Course.

The Order
of the Pla-
nets.

Plate II, Fig. 1.

The antient
Pythago-
rean Sy-
stem.

THIS was the antient System of the World, which was at first introduced into Greece by the great *Pythagoras*, and his Disciples, who had learned it from the wise Men of the East, to whom

whom, as to an University, they then all resorted Lect. III.
 for Instruction. 'Tis true, the other apparent System, which supposes the Earth immoveable, and the Heavens to revolve about it, was received among the vulgar and illiterate Part of Mankind; yet the Philosophers retained the true System, 'till *Aristotle*, and the Philosophers that came after him, degenerating from their Predecessors, and not being acquainted with true Philosophy, embraced the common System of the Vulgar: So that the antient System was forgot, and not minded, 'till the Time of *Nicolaus Copernicus*, who again brought it to Life, and retrieved it from Oblivion, and established it by solid Arguments and Reasons: Whence this System is now called the *Copernican System*. After the Invention of Telescopes, the Secondary Planets, with many new and unthought of Appearances, were observed in the Heavens by the *Astronomers*, which did wonderfully enlarge the antient System, and confirm'd it with invincible Demonstrations.

IF a Spectator should with a Telescope more nearly view the Planets, he will soon find, that they are spherical Bodies, and opake, like our Earth; having no proper Light of their own, but that they shine with the borrowed Light of the Sun; for that Side of them which is turned towards the Sun, is always illuminated; and it is by the reflected Light of the Sun, that they become visible: But the Side opposite to the Sun, which the borrowed Rays cannot reach, remains dark and obscure. And besides this, as all opake Bodies do, the Planets cast a Shadow behind them, which is always opposite to the Sun. The Line in the Planet's Body, which distinguishes the lucid Part from the obscure, appears sometimes right, sometimes crooked: And it is sometimes convex towards the splendid Part, and concave on the obscure; sometimes, on the contrary, it appears convex towards the obscure Side and concave towards the shining Face of the Planet, according to the different situation of the Eye in respect of

The Planets are opake spherical Bodies.

Lect. III. the Planet, and of the Sun which illustrates the Planet ; which different Position is likewise the Cause why sometimes we see a greater, sometimes a lesser Portion of the illuminated Face ; as it ought to be in spherical opake Bodies, which are exposed to the bright Light of the Sun.

The Secondary Planets.

THREE of the Planets, viz. The *Earth*, *Jupiter*, and *Saturn*, have other lesser Planets, which continually accompany them ; these are called Secondary Planets, Moons or Concomitants ; for they constantly keep close to their respective Primaries, and always attend upon them in their Circulation round the Sun ; and in the mean Time each of them performs his proper Revolution round his proper Primary. The *Earth* indeed has only the *Moon* to keep her Company, who never forsakes her in her annual Course round the *Sun*, and while she attends upon us, she performs proper Circulations of her own round the *Earth*, in the Space of a Month.

The Earth is accompanied by the Moon.

THAT the *Moon* appears so large to us, and shines so brightly beyond all the *Stars*, and in Bigness seems to equal the *Sun*, is owing intirely to her Nearness to the *Earth* ; for a Spectator in the *Sun* would scarcely be able to observe her without a Telescope ; and therefore, if she were as far removed from us as the *Sun*, she would be so small, as scarcely to be visible by an Eye that is not assisted by a Glass.

Jupiter's four Moons.

JUPITER has four *Moons* that attend him, which at different Distances, and with different Periods, perform constant Circulations round him ; that which is next to him, is no further removed than $2\frac{1}{6}$ of his own Diameters, and turns round in one Day, eighteen Hours and an half. The second, at the Distance of $4\frac{1}{2}$ Diameters, describes its Orbit in the Space of three Days, and thirteen Hours. The third is removed from *Jupiter*, seven of his Diameters, and finishes his Circulation in seven Days, four Hours. The furthestmost completes his Period in the Space of 16 Days, $16\frac{1}{2}$ Hours, at the Distance of 12 Diameters of *Jupiter*.

THESE

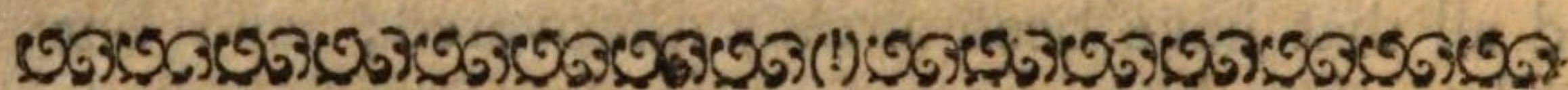
THESE Jovial Planets were first observed by Lect. III. that noble *Italian* Philosopher *Galileus*, by the Help of the Telescope which he first invented; and by them he increased the Number of the Celestial Bodies, and called them *Medicean* Stars, in Honour of the Dukes of *Tuscany*, with whose Name he dignified them. By the Benefit of these new-discovered Worlds, *Astronomy* and *Geography* have received many particular Advantages.

SATURN performs his Course round the Sun with no less than five Attendants, tho' most of them, by reason of their great Distance from the Sun, and the Smallness of their own Bodies, are not to be seen but by the Help of very long Telescopes: The acute Eyes of Mr. *Cassini* the *French* King's *Astronomer*, were the first that reached all that have been already discovered; and but of late they have been seen in *Britain*, by means only of that Telescope which was given to the ROYAL SOCIETY by the illustrious Mr. *Hugens*. The Distances of these Planets from *Saturn*, and their Periodical Times, are as followeth. The nearest completes his Revolution in one Day and $\frac{7}{8}$, and is distant from *Saturn's* Center $4\frac{3}{8}$ of his Semidiameters. The second revolves about *Saturn* in 2 Days 17 Hours, and the Semidiameter of his Orbit is $5\frac{3}{4}$ of the Semidiameters of *Saturn*. The third finishes his Revolution in 4 Days and 12 Hours, at the Distance of 8 Semidiameters. The fourth completes his Period in 16 Days, and is distant from *Saturn* 18 of his Semidiameters. The fifth and outermost takes $79\frac{1}{2}$ Days to finish his Course, and is 54 Semidiameters of *Saturn* distant from him.

BESIDES these Attendants, *Saturn* has an Ornament peculiar to himself; for he is dignified with a Ring which surrounds his Middle, and does no-where touch his Body; but by an exact Libration and Equiponderancy of all its Parts, sustains itself like an Arch; and being thus suspended by *Geometry*, it is kept from falling upon his Body. The Diameter of this Ring is more than double of

Saturn's
Ring.

Lect. IV. of the Diameter of *Saturn*; and tho' the Thickness
 of this Ring on the convex or concave Side be
 but small, yet its Breadth or Depth is so great,
 that it takes up the Half of that Space which is
 between its outward Surface and the Body of
Saturn, the rest of the Space remaining void: So
 that in proper Situations we can see the Heavens
 between the Ring and the Body. For what Pur-
 pose this admirable Ring was made, we know
 not; and perhaps we never may come to the
 Knowledge of it, since we find nothing in Na-
 ture like it; but yet we cannot but admire the In-
 finite Majesty and Power of GOD, who in this
 our Age, has discovered and shewed us new and
 unthought of Instances of his Greatness.



LECTURE IV.

*In which is proved that the System Ex-
 plained in the former Lecture, is the
 true System of the World.*



T may perhaps be objected against the
 System of the World delivered in our
 last Lecture, that we feigned and
 imagined our Spectator carried up
 into Heaven, and from thence to have
 seen with his Eyes the Motions, Situations, and
 Order of the Planets which we there explained.
 But this was only done in Imagination, and there-
 fore being nothing but a Fancy or Fiction, the
 System we have given upon that Supposition,
 will be likewise only a Fiction or Hypothesis,
 and may not answer to the Reality of Things. Can
 there not, by the same Liberty of Fancy, any
 other Order of the Planets be supposed, and another
 System be given quite different from ours? Can-
 not

not we, relying upon our Senses, place the Earth Lect. IV. in an immoveable Position, and suppose the Sun and Planets, and all the Stars, to move round it, as our Eyes testify to us that they do? And from such Positions cannot we explain all the Appearances of their Motions?

I answer, that altho' we fancied our Spectator raised up to the Heavens, and from thence to have looked upon the Sun and Planets; yet the Order, Motions, and Positions of the Planets, which would be seen upon that Supposition, and which we explained in the preceding Lecture, is no Fancy, or Fiction of the Imagination, but is as real, certain, and indubitable, as if a Spectator were there, and saw it with his Eyes. A *True Astronomy admits of no Fictions, or Hypotheses.* true *Astronomer* feigns nothing without solid and sufficient Reasons, he takes Nature for his Guide and Rule, and lays his Foundations on Observations: He raises his System upon Physical Causes, and invincible *Geometrical* Demonstrations, with which, as with an indissoluble Cement, he joins and binds the whole Fabrick together. The *Hypotheses* of *Ptolemy* and *Tycho* may truly be called Fictions; for they have nothing in them but a bare Supposition, on which without any Reason they depend; and they distort and disorder the whole Frame of Nature. But the true *Astronomy* is the most antient of all; for it was preserved in the School of the *Pythagoreans*, to whom it was delivered by the first *Astronomers*, either *Egyptians* or *Chaldeans*: It has all its Parts fitly joined together in a most agreeable Harmony and Order; it leads us to the Knowledge of the Universe, and the wonderful Symmetry, Beauty, and regular Disposition of all the Bodies that compose it. There is nothing in Nature that does more shew the piercing Force of human Understanding, the Sublimity of its Speculations, and deep Researches, than true *Astronomy*. It raises our Minds above our Senses; and even in Contradiction to them, shews us the true System of the World: The Faculty of Reason by which we have made,

Lect. IV. made these great Discoveries in the Heavens, must needs be derived from Heaven, since no earthly Principle can attain so great a Perfection. And since the Origination of our Minds is from Heaven, it may be expected, that they will endeavour to return thither, and Heaven will become our final Habitation: We will here declare in few Words, some of the Ways by which the Mind arrived to the Knowledge of these heavenly Discoveries.

A Demonstration that the Planets turn round the Sun.

Plate II.
Fig. 2.

FIRST, it is certain that where-ever the Sun be placed, the Orbit of *Venus* does surround him, and includes him within itself; and therefore *Venus*, while she describes this Orbit, does really turn round the Sun; for *Venus* has been observed to be above or beyond the Sun, sometimes it has been seen below it, or between the Sun and us. That *Venus* ascends above the Sun, is plain from hence, that when she is in Conjunction with the Sun, that is, when she is seen from the Earth, near the same Part of the Heavens that the Sun is in, her lucid Face appears in a full and round Figure: For since all the Planets borrow all the Light with which they shine, from the Sun, it is necessary that that Face of hers should be lucid, which is towards the Sun, and that which is turned from him, be involved in Darknefs; and therefore when she shines with a full and round Face, that Side of her which is towards the Sun, is also towards the Earth; and therefore, at that Time, she must be above the Sun; for in no other Position, could her illuminated Face be towards the Earth, when she is seen in Conjunction with the Sun. In the Figure, let S represent the Sun, T the Earth, and let *Venus* be in F or V, where she can be seen from the Earth, in the same Part of the Heaven that the Sun is; and she will appear to have a full and round shining Face; because that Side of her which is illuminated, and is towards the Sun, is likewise turned towards the Earth; and therefore the Place of *Venus*, in that Case, must necessarily be above the Sun. That

Venus

Venus is also sometimes below the Sun, or between the Sun and us, is evident from hence; that sometimes, when she is in Conjunction with the Sun, she either quite disappears, or, if she is visible, she appears horned, and takes exactly the Shape of a new Moon: And therefore that Face of hers which is towards the Sun, either is wholly turned from the Earth as in G; or only a very small Part of the illuminated Face towards the Earth; and can be seen by its Inhabitants, as in H, in which Case she assumes a horned Figure as the Moon does; and therefore at that Time she must of Necessity be placed between the Sun and us, and come lower or nearer to us, than the Sun is. Once *Venus* was seen within the Body or Disk of the Sun; but there was but one Man who had the Happiness to be Witness of the Sight, our Country-Man Mr. *Horrox*, who in the Year of Christ 1639, observed it with his Telescope to enter upon the Body of the Sun like a black Spot. This is a Sight which can seldom be observed; for it will not be seen again in the Sun's Body, 'till the Year 1761, upon the 26th Day of the Month of *May* in the Morning; at which Time all our *Astronomers* will, no doubt, be busy in making their Observations; for by them our Distance from the Sun can be nearly determined, which before that Time is not easily to be ascertained. Besides this, *Venus* is always observed to keep near the Sun, and in the same Quarter of the Heavens that he is; for she never recedes from him beyond a certain Distance of about 45 Degrees; so that she never comes in Opposition to the Sun, or to be seen in the *East* when he is in the *West*; nay, she never attains or arrives at a Quartile Aspect with him, or to have a fourth Part of the Heaven between her and him, which would necessarily happen, did she perform her Period round the Earth either in a longer, or shorter Time, than the Sun does.

AFTER the same Manner *Mercury* always keeps The Ap-
himself in the Neighbourhood of the Sun, and pearances of
never recedes from him so far as *Venus* does: Mercury are
like those of
He Venus.

Lect. IV. He hides himself so much in the Splendor of the Sun's Rays, that he is but seldom seen by us on the Earth; but since the Invention of Telescopes, he has been frequently observed, when in Conjunction with the Sun, to pass under his Disk like a black Spot, as *Venus* was seen by Mr. *Horrox*: The exceeding Brightness by which *Mercury* outshines all the Planets, does evidently prove him to be much nearer the Sun than any of the rest; for the nearer any Body is to the Sun, the greater is the Illustration it receiveth from him. From all this it is evident, that *Mercury* does likewise go round the Sun in a lesser Orbit, included within the Orbit of *Venus*; which therefore must necessarily be his Place, for no other can be assigned him.

The Orbit of Mars includes the Sun within it, and likewise the Earth.

MARS is not like *Mercury* and *Venus*; for he often comes in Opposition to the Sun, and appears to rise in the *East*, when the Sun sets in the *West*; and therefore his Orbit includes the Earth within it, and not only the Earth, but it necessarily includes the Sun likewise; for *Mars*, when he is seen near the Conjunction with the Sun, if he were between the Sun and Earth, would either quite disappear, or appear horned in the same Shape that *Venus* and the Moon have in that Position; but he always preserves a full, round, and shining Face, except near his *Quadrat Aspect*, that is, when there is about a fourth Part of the Heavens between the Sun and him; then he is observed to be somewhat gibbous, like the Moon, three or four Days before or after the *Full*.

Plate II.
Fig. 3.

LET S represent the Sun, T the Earth, and the Circle MNPR the Orbit of *Mars*; it is plain that *Mars*, in both M and P, must shine with a full Face upon the Inhabitants of the Earth, because that in both these Positions his Face, which is towards the Sun, and by it illuminated, is likewise towards the Earth: But in N and R, he will appear a little gibbous or deficient from Full. Besides, *Mars*, when he is seen in Opposition to the Sun, looks almost seven times larger,

in

in Diameter, than when he is near to a Conjunction Lect. IV. with him; and therefore he must needs be seven times nearer to the Earth in the one Position than in the other. From hence it is plain, that tho' the Earth lies within the Orbit of *Mars*, yet it is not near to the Center of his Orbit: But *Mars* always keeps nearly at the same Distance from the Sun, and therefore it is evident, that it is not the Earth, but the Sun, which *Mars* respects as the Center of his Motions: For *Mars* seen from the Earth appears to move very unequally, sometimes to go faster, sometimes slower; sometimes he scarcely seems to move at all, and sometimes he even goes with a backward Motion; whereas a Spectator in the Sun would always see *Mars* go forward in the same uniform Tenor: And therefore it is most evident that the Sun is the Center, and not the Earth, of *Mars's* Motions. Again, since the same Appearances are observed in *Jupiter* and *Saturn*, as in *Mars*, (though the Disproportion or Difference of the Distances is not so great in *Jupiter*, as in *Mars*; nor so great in *Saturn*, as it is in *Jupiter*) and the Motions of these two Planets are no ways uniform round the Earth; yet from the Sun their Motions will be seen to be regular and orderly: It is plain from hence, that the Sun and not the Earth, is in the Center of all the Orbits of the Planets. The Place of the Earth we have demonstrated to be without the Orbits of *Mercury* and *Venus*, and within the Orbit of *Mars*; and therefore its Place must needs be between the Orbits of *Venus* and *Mars*: And from thence it follows, that the Earth itself must turn round the Sun; for if it stood still, since it lies within the Orbits of the superior Planets *Mars*, *Jupiter*, and *Saturn*, we might indeed observe the Motions of those Planets from the Earth, to be very unequal and irregular; but they would never appear to stand still, or to go backwards, so long as the Orbits themselves are quiescent, as we demonstrated in our first Lecture. Since therefore the Stations and Retrogradations

The Earth
is not in the
Center of
Mars's Or-
bit.

The same
Appearances
of Jupiter
and Saturn.

The Earth
moves in an
Orbit round
the Sun.

Lect. IV. tions of these Planets are observed from the Earth; and since the Position of the Earth, or Place that it obtains in the System, is in the Middle of the moveable Bodies, having *Mercury* and *Venus* on one Side nearer to the Sun, and *Mars*, *Jupiter*, and *Saturn*, on the other Side, more remote; it being of the same Nature as they are, must likewise have the same Sort of Motions; and as the Earth is in the middle Place between *Venus* and *Mars*, so its Period likewise, in which it performs its Course round the Sun, is also a Mean between the Periods of *Venus* and *Mars*, being greater than the one, and less than the other: For *Venus* describes her Orbit in eight Months; the Earth in a Year; but *Mars* takes near two Years to finish his Course.

A Demonstration of the Earth's Motion.

THERE is another Demonstration of the Earth's Motion drawn from Physical Causes, for which we are indebted to the admirable Discoveries of the incomparable Sir ISAAC NEWTON: He has demonstrated, that all the Planets gravitate towards the Sun: And Observations testify to us, that either the Earth turns round the Sun, or the Sun round the Earth, in such a Manner as that they describe equal *Area's* in equal Times. But Sir ISAAC has demonstrated, that whenever Bodies turn round each other, and regulate their Motions by such Law, the one must of Necessity gravitate to the other; and therefore, if the Sun in its Motion does gravitate to the Earth, Action, and Re-action being equal and contrary, the Earth must likewise gravitate to the Sun. He has likewise demonstrated, that when two Bodies gravitate to one another, without directly approaching one another in right Lines, they must both of them turn round their common Center of Gravity. The Sun and Earth therefore do both turn round their common Center of Gravity. But the Sun is so great a Body in respect of the Earth, which is but a Point, as it were in comparison, of the Sun, that the common Center of Gravity, of the Earth and Sun, must lie within the Body of the

Sun itself, and not far from the Center of the *Sun* : The *Earth* therefore turns round a Point which is within the Body of the *Sun*, and therefore turns round the *Sun*. This Argument drawn from Physical Causes I take to be unanswerable. Lect. IV.

COMPARING the Periods of the *Planets*, or the Times they take to finish their Circulations, with their Distances from the *Sun*, we find they observe a wonderful Harmony and Proportion to one another ; for the nearer that any *Planet* is to the *Sun*, the sooner does he finish his Circulation, and his Motion is the quicker : And in this there is a constant and immutable Law, which all the Bodies of the Universe inviolably observe in their Circulations ; viz. That the Squares of their Periodical Times are as the Cubes of their Distances from the Center of their Orbits, about which they perform their Motions regularly. A wonderful Harmony observed between the Periods of the Planets, and their Distances from the Sun.

The most sagacious *Kepler* was the first who discovered this great Law of Nature in all the Primary *Planets* ; afterwards the *Astronomers* observed, that the Secondary *Planets* did likewise regulate their Motions by the same Law ; and that in the two Systems of Bodies revolving about *Jupiter* and *Saturn*, this Rule is constantly observed, that the Squares of their Periodical Times are as the Cubes of their Distances from their respective Primaries. Thus the *Moon* or *Satellite* that is next to *Jupiter*, is distant from *Jupiter's* Center $2\frac{1}{6}$ of *Jupiter's* Diameters, and he performs his Period in 42 Hours. The outermost *Satellite* describes his Orbit in 402 Hours. Say therefore, as 1764 the Square of 42, is to 161604 the Square of 402 ; so is $\frac{42^3}{2\frac{1}{6}^3}$ the Cube of $2\frac{1}{6}$, to a fourth proportional Number, which by the *Golden Rule* will be found nearly $\frac{420000}{2\frac{1}{6}}$; out of which Number extract the Cube Root, and we have $2\frac{1}{6}$ or $12\frac{2}{3}$ for the Distance of the furthest *Satellite* from *Jupiter*. Now the Observations of all *Astronomers* confirm, that this is the true Distance of that *Satellite* from the Center of *Jupiter*, and the same Thing is to be observed

D in

Lect. IV. in all the rest, as likewise in the *Satellites* of *Saturn*.

Sir Isaac
Newton
first disco-
vered the
Reason and
Cause of this
Harmony.

THE Reason of this Law was unknown to *Kepler*, for he found it out only by Computation, comparing the Distances of the *Planets* with their Periods. But the Glory of investigating it from its proper Cause, and demonstrating the Physical Necessity of this Law, was reserved for the Great *Sir Isaac Newton*, who has demonstrated, that without a total Subversion of the Laws of Nature, no other Rule could take place in the Circulations of the Heavenly Bodies.

SINCE therefore all *Astronomers* do unanimously agree, that the Law we have above explained, is constantly observed by 14 great Bodies, of which there are more than one that turn round a common Center, viz. five Primary *Planets* and nine Secondaries: And since the *Moon* turns round the *Earth*, if the *Sun* did likewise perform his Circuits round it, according to this Law of Nature, the *Moon* and *Sun* ought to regulate their Motions in the same Manner; and therefore since the *Moon* finishes her Course in 27 Days, and the *Sun* in 365, and the Distance of the *Moon* is known to be about 60 Semidiameters of the *Earth*; if we say, as 729 the Square of 27 is to 133225 the Square of 365, so is 216000 the Cube of 60 to another, which will be 39473251, the Cube Root thereof being 340, ought to express the Distance of the *Sun* from the *Earth*, provided he governed his Motion by the same Law that all other Bodies do. Now the *Astronomers* prove by invincible Reasons, that the *Sun* is more than 30 times further from the *Earth* than 340 Semidiameters of the *Earth*; for it cannot well be supposed so little as 10000 Semidiameters: According to which Distance it could not turn round the *Earth* in less than 164 Years, if it observed the same Law which all other Bodies do.

Now

Now it is certain that the *Sun* does either Lect. IV.
 turn round the *Earth*, or the *Earth* round the *Sun*, once in a Year. But if the *Sun* should be If the Sun
turned
round the
Earth, this
Harmonical
Rule would
not univer-
sally hold.
 made to turn round the *Earth*, the universal Law
 of Nature would thereby be violated, the Har-
 mony and Proportion of the Motions destroyed,
 and a Confusion and Disorder introduced into the
 Frame of the Universe. But if the *Earth* be
 made to go round the *Sun* in the Space of a Year,
 it will then perform its Circulation according to
 the same Law which the other *Planets* observe;
 and without the least Exception there will be a
 most beautiful Order and Harmony of Motions
 every-where preserved thro' the whole Frame of
 Nature.

As we discover the mutual Relations and Like-
 ness of Nature that is in the *Planets*, in that
 they are like our *Earth*, Opake, Spherical Bo-
 dies, which are illustrated and shine with the bor-
 rowed Light of the *Sun*, round whom they all
 circulate, as we have said, with a regular Har-
 mony and Order: So likewise the *Sun* and all the
fixed Stars which shine with their own native
 Light, and remain immoveable in their Places,
 are to be considered as Bodies of the same Kind
 and Nature. The Reason why our *Sun* appears to
 us so great and bright in comparison of the *Stars*,
 whose weaker Lights disappear as soon as the *Sun*
 begins with his Beams to refresh and illustrate our
 Habitation, is, that the *Earth* at an immense Di-
 stance from all the rest of the *Stars*, keeps near to
 the *Sun*, round whom she always circulates; for a
 Spectator placed as near any of them as we are to
 our *Sun*, would see a Body as big and bright as
 the *Sun* appears to us, and every Way like our
Sun. A Spectator as far distant from our *Sun* as
 the *fixed Stars* are from us, would observe our
Sun as small as a *Star*, and no doubt would rec-
 kon the *Sun* as one of them in numbering the
Stars. All the *fixed Stars* therefore are *Suns*, and
 the *Sun* differs in nothing from a *fixed Star*.

Lect. IV. ALTHO' the *Earth* is at such a Distance from the *Sun*, that if it were to be seen from his Body, it would appear no bigger than a Point; yet that Distance is so very small in comparison of the exceeding great Distance of the nearest *fixed Star*, that if the whole Orbit, in which we have said the *Earth* moves round the *Sun*, were seen from a *Star*, it would appear likewise no bigger than a Point. For the Angle under which the whole Diameter of the *Earth's* Orbit appears, is so very small, that our quickest and most sharp-sighted *Astronomers* can scarcely observe it. They who have been most diligent in observing this Angle, (which they call the Parallax of the great Orbit, that is, of the Orbit in which the *Earth* moves) have always found it to be less than a Minute; and therefore the *fixed Stars* must be at least 10000 times further from us, than we are from the *Sun*.

HENCE it follows, that tho' the *Earth* approaches nearer to some *fixed Stars* at one Time of the Year, than it does at the opposite Time, and that by the whole Interval of the Diameter of its Orbit, the *Stars* will not upon that Account seem bigger when it is nearest to them, nor will the visible Position of any two *Stars* be sensibly changed by the Motion of the *Earth*. For even here on *Earth*, if there be two Towers that are near to one another, if they are to be seen by a Spectator who is ten Miles distant from each, if this Spectator approach nearer to them only by one Pace, which is the ten thousandth Part of the Distance, he only approaching by so small a Space, can no ways perceive the Towers bigger, or their Distance from one another greater. After the same Manner the *Earth* approaching a *fixed Star*, and coming nearer to it by the ten thousandth Part of the Distance between the *Earth* and it, a Spectator on the *Earth*, upon the Account of so small a Change of Place, will not find thereby any sensible Difference either of the Magnitude or Position of the *Star*.

HENCE

HENCE it follows, that if the *Sun* were as far distant from us as the *Stars* are, that is 10000 Semidiameters of the *Earth's* Orbit, it would appear 10000 times less, or under a smaller Angle than it does now. Now the Angle under which the *Sun* appears to us, is about half a Degree or 30 Minutes; if the *Sun* were removed as far from us as the *fixed Stars* are, he would be seen under an Angle of but the thousandth Part of three Minutes; that is, under an Angle no bigger than ten *Thirds*, which is altogether imperceptible; and no bigger would the Angle be under which a Spectator placed among the *fixed Stars* would observe the *Sun*. Lect. IV.
The Angle under which the Sun would appear seen from a fixed Star.

AGAINST this Position of ours some may object, that if the Distance of the *Stars* be so great, they themselves must be vastly larger than our *Sun*; for they cannot, according to them, be less than a Sphere, whose Semidiameter equals the Distance between the *Sun* and us; for they assert, that the *Stars*, at least those of the first Magnitude, are seen under an Angle at least of one Minute: But the Orbit of the *Earth* seen from the *fixed Stars* does not subtend a greater Angle; and therefore the Diameter of the *Stars* is not less than the Diameter of the *Earth's* Orbit. Now that Sphere whose Semidiameter equals the Distance between the *Sun* and *Earth*, is a Million of times greater than the *Sun*; consequently the *fixed Stars* must be at least a Million of times greater than our *Sun*: Since therefore there is such enormous Difference in their Bigness, it cannot be supposed that the *Sun* and *fixed Stars* are Bodies of the same Kind.

BUT they who ascribe such immense Magnitude to the *fixed Stars*, are much deceived in their Measures; for their apparent Diameters are not near so great as they suppose them to be: For really these Diameters are so extremely small, that if they be rightly observed, they appear like so many shining Points without any Breadth or Diameter at all; and there can be no Observations The fixed Stars have no apparent Diameters, but look like Points.

Lect. IV. nice enough, by which the Minuteness of their
 ~~~~~ Diameters can be measured, or reduced to any  
 determined Quantity. We observe about all fla-  
 ming and shining Bodies in the Night, a kind  
 of Irradiation or luminous Appearance, by which  
 their Diameters are seen a hundred or many  
 more times bigger than they are; as it is plain  
 by the Experiment of a Candle placed at a  
 great Distance, whose Flame seems to be much  
 larger than it is when we come near it. This  
 Irradiation is much diminished, if they are look-  
 ed at thro' a small Hole made with a Pin in Pa-  
 per; but it is easier and more nicely taken away,  
 when they are seen thro' a Telescope, which  
 destroys the adventitious Rays, and shews us the  
*fixed Stars* as so many lucid Points. Now tho'  
 Telescopes do increase the Diameters of Bodies  
 very much, yet the *fixed Stars* seen thro' them  
 appear still so small, that we have no Measure  
 of any determined Magnitude, but what is greater  
 than theirs seem to be; a Telescope magnifying  
 a hundred times, shews them only like shining  
 Points; and therefore I cannot but wonder why  
*Ricciolus* should suppose the apparent Diameter  
 of the *Dog-Star* or *Sirius* to be 18 Seconds;  
 for if that were the Angle he subtended to  
 the naked Eye, a Telescope which magnifies  
 200 times, would shew that *Star* under an Angle  
 of 3600 Seconds or one Degree, so that he would  
 appear to have a Disk four times greater than  
 the *Sun* and *Moon* have. And yet Observation  
 testifies, that such a Telescope shews us *Sirius* no  
 bigger than a Point, at least not larger than the  
 Planet *Mars*: But *Mars*, when he is nearest us  
 and biggest, subtends an Angle of about 30 Se-  
 conds; therefore, if the Diameter of *Sirius* mag-  
 nified 200 times is but 30 Seconds, its apparent  
 Diameter without magnifying will be the 200th  
 Part of 30 Seconds, or  $\frac{3}{20}$  of a Second, that is  
 nine third Scruples or Minutes, or nearly equal  
 to the *Sun* when it is seen at the Distance of  
 the *fixed Stars*, as we shewed before: The  
*Sun*

Which is  
 demonstra-  
 ted by the  
 Telescope.



*Sun* therefore and *Sirius* are nearly of the same Lect. IV. Magnitude and Dimensions, and may be esteemed Bodies of the same Kind. ~~~~~

SINCE the *fixed Stars* appear so small, and subtend at the Eye such unperceivable Angles, some will wonder how they come to be at all seen, since there are Bodies which would shew themselves under larger Angles, that are yet so small as not to be looked at without a Microscope: But all flaming and fiery Bodies can be seen at great Distances, even at such from whence other Bodies, which have as large apparent Diameters, do quite disappear, and become invisible. Thus the Flame of a Candle in the Night-time is easily perceived at the Distance of two Miles, whereas in the Day-time an opaque Object, tho' strongly illustrated by the *Sun*, and six times bigger than the Flame of a Candle, is not to be observed with the naked Eye at that Distance. For the native Light that these fiery and flaming Bodies send forth, is stronger and more piercing, and acts upon the nervous Fibres of the *Retina* with a greater Force, than the Light reflected from opaque Objects; for all Light is much weakened by Reflection. And it is upon the account of this brisk and strong Light which flows from fiery Bodies, and which makes so sensible Impressions on the *Retina*, that such Bodies are judged to be so big in comparison of others which affect us with a weaker Light.

HENCE it is evident, that all these *Stars* which remain immoveable in the Heavens, are Bodies of a fiery Nature, as our *Sun* is, nor are they much less, nor much bigger than he is, and therefore are to be esteemed as so many *Suns*. It is not to be imagined, that all these *Suns* are planted in one concave Surface of a Sphere, so as to be all equally distant from us; but it is more reasonable to suppose that they are spread everywhere thro' the vast indefinite Space of the Universe, and that they are at great Distances from one another; so that there may be as great Distance

*The fixed Stars are luminous fiery Bodies.*

*The fixed Stars are Suns.*



Lect. IV. between any two *Suns* that are next to one another, as there is between our *Sun* and the nearest *fixed Star*. Hence a Spectator who is near any one *Sun*, will only look upon him to whom he is nearest as a real *Sun*, and the rest he will consider as so many small shining *Stars* fixed in his Heaven or Firmament.

It is no ways probable, that God Almighty, who always acts with infinite Wisdom, and does nothing in vain, should create so many *Suns*, and place them alone in indefinite Space, at such great Distances from each other, and not have made other Bodies, which he has placed near them, to be nourished, animated, and refreshed with the Heat and Light of these *Suns*: Those who affirm, that God created these great Bodies only to give us a small dim Light, must have a very mean Opinion of the Divine Wisdom. It is more reasonable to suppose, that every *Sun* is surrounded with a Company of *Planets* peculiar to himself, which in different Periods, and at different Distances, perform their Circulations round their proper *Sun*; and who knows but that some of these *Planets* may have *Moons*, and other Bodies, to attend them in their Circulations?

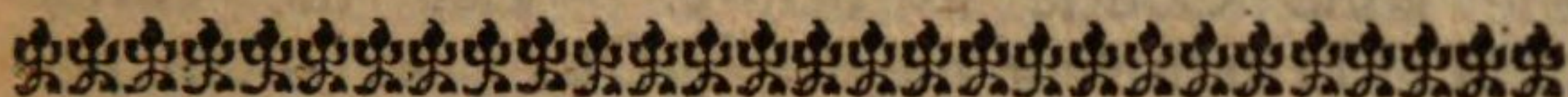
An Idea of  
the Uni-  
verse.

HENCE we may frame to ourselves an admirable magnificent *Idea* or Notion of the Vastness or Amplitude of the World, by imagining an indefinitely great Space of the Universe, in which there are placed innumerable *Suns*, which, tho' they appear to us like so many small *Stars*, yet are Bodies which are not behind our *Sun* either in Bigness, Light, or Glory; and each of them constantly attended with a Number of *Planets*, which dance round him, and constitute so many particular *Worlds* or Systems: Every *Sun* doing the same Office to his proper *Planets* in illustrating, warming, and cherishing them, that our *Sun* performs in the System to which we belong.

HENCE we are to consider the whole Universe as a glorious Palace for an infinitely Great and every-where-present God; and that all  
the



the *Worlds* or System of *Worlds*, are as so many Lect. V. Theatres, in which he displays his Divine Power, Wisdom and Goodness.



## LECTURE V.

*Of the Solar Spots. Of the Rotation of the Sun and Planets round their Axes : And of the fixed Stars.*



PON the Account of the great Distance of the *Sun* from us, the Convexity of his Body cannot be perceived by our Sight; nor is this a Wonder since the *Moon*, which is much nearer

*The Convexity of the Sun and Moon cannot be perceived by our Eyes.*

to us, cannot be seen as a globular Body: But both *Sun* and *Moon* shew themselves to us, as if they were circular Planes, which we call Disks: And a Point in the Middle, which is really in the Surface, is said to be the Center, or the Apparent Center of the Disk.

IF the *Sun* thro' all its Parts were every-where equally bright, and shined with the same Lustre, he might turn round his own *Axis*, and that Rotation no ways be perceptible, nor to be discovered by our Senses. But since in the most clear and lucid Body of the *Sun*, and in its purest Flame, many black Spots have several times been observed, it is by their Motion that we discover the Rotation of the *Sun* round its *Axis*: For these Spots have been observed to have first appeared near the Margin of the *Sun*, and then by Degrees to have crept towards the Middle, or Center of his Disk; and from thence going still forward, have arrived at the opposite Side or Edge of the Disk, where they have set or disappeared; and

*Dark Spots on the Sun's Body.*



Lect. V. and some of them after setting, being hid or absconded in the opposite Side of the *Sun* for the Space of about fourteen Days, have again appeared in the Margin, and shewed themselves, taking the same Course as before. Let the Circle AGHD represent the *Sun's* Disk; we often observe some dense and obscure Substances, like our thick and terrestrial Clouds, to appear in the Limb or Edge at A, which by Degrees move towards B, and at last arrive at the Middle of the Disk; after which, still going forward, they shew themselves in the opposite Point of the Circumference at D; where after a little Stay, they at last vanish and disappear.

Plate II.  
Fig. 4.

The Sun  
turns round  
his Axis.

SOME of these Spots have been observed to rise in the Limb, and having traversed the Disk, and set, after the Space of twenty-seven Days, have again been seen to rise where they first appeared; and the Time they take to move thro' the Surface of the *Sun* opposite to us, during which Time they are invisible, is just and equal to the Time in which they pass over the visible Disk. The Motion of these Spots in the Margin, at A or at D, appears to be slow; when they come towards the Middle they seem to move quicker, and to describe larger Spaces: Their Figures likewise change; for in the Limb they are seen more contracted and narrow, near the Center they look broader and larger; these Appearances exactly answer to the Motion of some dense and dark Bodies, which swim upon the Surface of the *Sun*, and are whirled by the vertiginous Motion of the *Sun* round his *Axis*.

SOME have imagined, that these Spots do not stick upon the Body of the *Sun*, but that they are at some Distance from him, and that they perform their Circulations round the *Sun* in the same manner as *Jupiter's* *Satellites* circulate round *Jupiter*. But such are easily refuted; for if the Spots were not on the Body of the *Sun*, but made their Circuits at a Distance from him, they could not be seen half the Time of their Period in



in the Body of the *Sun*; for suppose the *Sun* in Lect. V. A be seen from the *Earth* at B, under the Angle  of 30 Minutes: If the Spot were not on the *Sun's* Plate II. Fig. 5. Body, but described the Circle F E G at some Distance from him; it could not be observed to pass under the *Sun*; 'till it came to E, where the right Line B D, touching the Disk, does cut the Orbit; and if we draw another Tangent to the Disk B G C, it would only be seen on the Surface of The Spots are on the Surface of the Sun. the *Sun*, while it described the Arch E G, which is much less than half the Periphery, and is described in much less Time than half the Period, in which the Spot performs its Circuit. Now we know by Observation, that those Spots which finish an entire Circulation, (for some of them have been observed to make four or five complete Revolutions before they were dissolved, each of which was 27 Days) have taken  $13\frac{1}{2}$  Days from the Time of their appearing, or rising on the *Eastern* Limb, to their Setting on the *Western*: And therefore, since the Spots are seen for half the Time of their Period upon the Body of the *Sun*, it is plain their Orbits must lie on the *Sun's* Surface.

MANY Spots seem to be generated in the very Spots generated in the Body of the Sun, and again are dissolved or dissipated. Middle of the Disk, where they first begin to appear: Others again seem to be dissolved, and to vanish there; sometimes several small ones gather together, and make a large Spot; and sometimes a large Spot is seen to be divided, and cut into many lesser ones. The great *Italian* Philosopher *Galileus* first discovered them with his Telescope. Afterwards *Scheinerus* did more accurately observe them, who has published a large Volume about them. When he observed them, there were then 50 visible in the *Sun*: From the Year 1650 to the Year 1670, there were rarely seen above one or two together; from that Time again many have been observed together; nor does there seem to be any certain Period of Time, or Law, for their appearing, and Vanishing or Dissolution.

HISTO-



Lect. V. HISTORIANS tell us, that the *Sun* has been observed for a whole Year to have appeared pale, without that Lustre and Brightness it usually gives; and that it hath not imparted its Heat and Light with the same Force and Vigour that it ordinarily does. It is probable, that this Weakness of Light did arise from a great Multitude of Spots which at that Time did beset the *Sun*, and covered a large Portion of his Surface: For now we frequently observe Spots which are larger or broader, not only than *Europe* or *Africk*, but what even equal, if they do not exceed, the Surface of the whole *Terraqueous* Globe.

*The Axis of the Sun is inclined to the Plane of the Ecliptick.*

THE Motion of the Spots is from the *West* to the *East*, and by observing the *Sun* nicely, we find that its *Axis* is not perpendicular to the Plane of the *Earth's* Orbit, which is called the Plane of the *Ecliptick*: But it is inclined, so as to make an Angle with the *Axis* of the Orbit, or with a Perpendicular to the Plane of the Orbit which passes thro' the Center of the *Sun*, which Angle is in Quantity about seven Degrees: And therefore the *Æquator* of the *Sun*, that is to say, the Circle which is in the Middle between the two Poles, cuts the Plane of the Orbit in a right Line, which Line produced will intersect the Orbit in two Points; and whenever the *Earth* comes to these two Intersections, the Tracts which the Spots describe will appear as right Lines, since the Eye of the Spectator is in the Plane of their Motion: But in all other Positions of the *Earth*, the Plane of the *Sun's* *Æquator* is either above or below the Eye of the Spectator, and the Lines in which the Spots are seen to move, appear crooked and seem to be *Ellipses*.

SINCE the most bright Body of the *Sun* is not without its Spots and Blemishes, we are not to imagine that the *Planets* are clear, and without their Stains and Marks. *Jupiter*, *Mars*, and *Venus*, when looked at through a Telescope, have several very remarkable ones; and it is by their Motions, that we conclude the Rotation of the *Planets*.

*The Planets likewise have Spots.*



*Planets* round their *Axes*, after the same Manner, Lect. V. and by the same Argument, that we proved the Rotation of the *Sun*. The Body of *Venus* performs its Revolution round its *Axis* in the Space of 23 Hours. *Mars* finishes his Rotation in 24 Hours and 40 Minutes. The *Earth* in a Day, which we collect from the apparent Revolution of the Heavens, and of all the *Stars* round it in that Time. All these Bodies in their Rotations go the same Way from the *West* to the *East*. They turn round their Axes.

JUPITER, besides Abundance of Spots, has some Jupiter's Belts. Bands or Girdles which surround him; they are parallel to one another, but they neither preserve the same Magnitude nor Distance; but sometimes they increase, sometimes they diminish their Breadth, sometimes they approach each other, sometimes they recede from one another, and undergo several Changes. In the Year 1665, M. *Cassini* discovered a very large Spot in *Jupiter's* Disk, which he observed continually for the Space of two Years, and determined accurately its Figure and Position in respect to his Girdles; but The Changes he undergoes. this Spot vanished in the Year 1677, and was not again seen 'till the Year 1679: Afterwards for the Space of almost three Years, it continually shewed itself, and then by Degrees withdrew itself from our Sight, and has since several times appeared and disappeared. In a Word, from the Year 1665, when it was first observed, to the Year 1708, it has eight times appeared and vanished. By its Revolutions we conclude, that the Body of *Jupiter* moves round his *Axis* in the Compass of 9 Hours and 56 Minutes.

It is probable that our *Earth* enjoys a more constant and settled State and Condition than *Jupiter*; for we observe greater Changes in his Surface, than what would happen to the *Earth*, if the Ocean should leave its Place, and overwhelm the Land, and give us a new Place, and a new Figure of the Sea, by changing the Places of Land and Water. But this is upon Supposition that these Spots are inherent in the Body of *Jupiter*:



Lect. V. *Jupiter*: But if they are only Clouds and Vapours swimming in his Atmosphere, then indeed the Inhabitants of *Jupiter* would have a more constant and permanent State of Weather, than what any Part of the *Earth* enjoys: I leave it to the *Philosophers* to determine which of these two Opinions is the most probable.

MERCURY does always keep so near the *Sun*, with so great a shining Lustre in all its Parts; and the Heaven, while he is seen, is so much illuminated, that there can be no Observations made to discover his Spots. And *Saturn* is so much further removed from us, more than the other *Planets*, that his Spots are not to be discerned: Yet it is probable that they, as well as the other *Planets*, have each a Rotation round an *Axis*, that all the Parts of their Surfaces may frequently have imparted to them the Light and cherishing Heat of the *Sun*, and may again be withdrawn from him, to receive such Changes as are proper and convenient for the Nature of each *Planet*.







## LECTURE VI.

*Of the Magnitude and Order of the fixed Stars. Of the Constellations, Catalogues of the Stars, and the Changes to which they are liable.*



THE *fixed Stars* appear to be of different Bignesses, not because they really are so, but because they are not all equally distant from us. Those that are nearest will excel in Lustre and Bigness; the more remote *Stars* will give a fainter Light, and appear smaller to the Eye. Hence arise the Distribution of *Stars*, according to their Order and Dignity, into *Classes*; the first Class containing those which are nearest to us, are called *Stars* of the first Magnitude; those that are next to them, are *Stars* of the second Magnitude: The third Class comprehends them of the third Magnitude, and so forth, 'till we come to the *Stars* of the sixth Magnitude, which comprehend the smallest *Stars* that can be discerned with the bare Eye. For all the other *Stars*, which are only seen by the Help of a Telescope, and which are called Telescopical, are not reckoned among these six Orders. Altho' the Distinction of *Stars* into six Degrees of Magnitude is commonly received by *Astronomers*; yet we are not to judge, that every particular *Star* is exactly to be ranked according to a certain Bigness, which is one of the Six; but rather in reality there are almost as many Orders of *Stars*, as there are *Stars*, few of them being exactly of the same Bigness and Lustre. And even among those

*The Distinction of Stars according to their Magnitude.*



Lect. VI. those *Stars* which are reckoned of the brightest Class, there appears a Variety of Magnitude; for *Sirius* or *Arcturus* are each of them brighter than *Aldebaran* or the *Bull's Eye*, or even than the *Star* in *Spica*; and yet all these *Stars* are reckoned among the *Stars* of the first Order: And there are some *Stars* of such an intermedial Order, that the *Astronomers* have differed in classing of them; some putting the same *Stars* in one Class, others in another. For Example: The little *Dog* was by *Tycho* placed among the *Stars* of the second Magnitude, which *Ptolemy* reckoned among the *Stars* of the first Class: And therefore it is not truly either of the first or second Order, but ought to be ranked in a Place between both.

The Constel-  
lations.

ASTRONOMERS not only mark out the *Stars*, but that they may better bring them into Order, they distinguish them by their Situation and Position in respect to each other; and therefore they distribute and divide them into *Asterisms* or *Constellations*, allowing several *Stars* to make up one *Constellation*. A *Constellation* is a System of several *Stars* that are seen in the Heavens near to one another: And for the better distinguishing and observing them, they reduce the *Constellations* to the Forms of certain Animals, as *Men*, *Bulls*, and *Bears*, &c. or to the Images of some Things known, as of a *Crown*, a *Harp*, a *Balance*, &c. The Ancients took these Figures from the Fables of their *Religion*: And the modern *Astronomers* do still retain them, that they may avoid the Confusion which would arise by making new ones, which would much perplex them, when they compared the modern Observations with the old ones.

Their Anti-  
quity.

THE Division of the *Stars* by Images and Figures is of great Antiquity, and seems to be as old as *Astronomy* or *Philosophy* itself: For in the most ancient Book of *Job*, *Orion*, *Arcturus*, and the *Pleiades*, are mentioned; and we meet with the Names of many of the *Constellations* in  
the



the Writings of the first Poets, *Homer* and *Hesiod*. Lect. VI.  
For it was necessary for the Advancement of *Astro-*  
*nomy* so to distinguish the *Stars*, and to bring them  
into some Order.

SINCE the Distance of the *Stars* is immensely great, it is no Matter in what Place of our Sy-  
stem the Observer resides, whether in the *Sun*, in  
the *Earth*, or even in *Saturn*, the outmost of all  
the *Planets*; for Spectators in each of those Places  
will see the same Face of the Heavens, the same  
*Stars*, with the same Magnitude, and the same  
Figure of the Constellations; and the Heavens which  
surround and involve them all, will have the same  
Face.

*The same  
Face of the  
Starry Fir-  
mament is  
observed  
from all  
the Planets.*

ASTRONOMERS divide the *Starry Firmament*  
into three Regions, the Middle of which compre-  
hends those *Stars* which have their Situation near  
the Planes of the Orbits in which the *Planets* move;  
this Part of Heaven they call the *Zodiack*, because  
the Constellations there placed, seemed for the  
most part to represent some *Animal* or living  
Creature. In this Space the *Planets* are always to  
be seen, and none of them ever transgress its  
Bounds: Upon each Side of this *Zone* lie the other  
two Regions of the Heavens, one of which is  
called the *North*; and the other, the *South* Part of  
the Heavens.

*The Regions  
of the  
Heavens.*

THE Antients divided the visible Firmament  
into XLVIII. Images, twelve of which filled the  
*Zodiack*, and they give their Names to the twelve  
Signs, or the Portions into which it is divided.  
Their Names are the *Ram*, the *Bull*, the *Twins*,  
the *Crab*, the *Lion*, the *Virgin*, the *Balance*, the  
*Scorpion*, the *Archer*, the *Goat*, the *Water-Bearer*,  
and the *Fishes*.

*The Images  
noted by the  
Antients,  
are 48.*

IN the Northern Region there are XXI. Images,  
viz. the *Lesser Bear*, the *Great Bear*, the *Dra-*  
*gon*, *Cepheus*, *Bootes*, the *Northern Crown*, *Her-*  
*cules*, the *Harp*, the *Swan*, *Cassiopeia*, *Perseus*, *An-*  
*dromeda*, the *Triangle*, *Auriga*, *Pegasus* or the  
*Flying-Horse*, *Equuleus*, the *Dolphin*, the *Arrow*,  
the *Eagle*, *Serpentarius*, and the *Serpent*: After-

E

wards



Lect. IV. wards they added to them two others, viz. that of *Antinous*, which was made of the *Stars* that are not included within any Image, and are near the *Eagle*: And the Constellation called *Berenice's Hair*, consisting of *Stars* which are near the *Lion's Tail*.

UPON the *South Side* of the *Zodiack* there are fifteen *Asterisms*, which were known to the *Antients*, viz. the *Whale*, the *River Eridanus*, the *Hare*, *Orion*, the *Great Dog*, the *Lesser Dog*, the *Ship Argo*, *Hydra*, the *Cup*, the *Crow*, the *Centaur*, the *Wolf*, the *Altar*, the *Southern Crown*, and the *Southern Fish*: To these are lately added XII. more Constellations, which are not to be seen by us who inhabit the *Northern Regions*, because of the *Convexity* of the *Earth*; but in the *Southern Parts* they are very conspicuous. These are the *Phoenix*, the *Crane*, the *Peacock*, the *Indian*, the *Bird of Paradise*, the *Southern Triangle*, the *Fly*, the *Chameleon*, the *Flying Fish*, the *Toucan* or *American Goose*, *Hydrus* or *Water Serpent*, *Xiphias* or the *Sword Fish*.

The Stars  
without  
Forms.

WITHOUT the *Compass* of the Constellations or Images, there are several *Stars*, which cannot be reduced to any of the *Forms* mentioned; and these are called *Unformed Stars*, out of which some great *Astronomers* have made new Constellations, as *Charles's Heart*, and *Sobieski's Shield*.

The Milky-  
way.

THE *Galaxy*, or *Milky-way*, is also to be reckoned among the Constellations: This is a broad Circle of a whitish Hue, like Milk; in some Places it is double, but for the most part it consists of a single Path, and goes round the whole Heavens. The great *Galileus*, with his Telescope, discovered that the Portion of the Heavens which this Circle passes thro', was every-where filled with an infinite Multitude of exceeding small *Stars*; which tho' they cannot, by Reason of their Smallness, be seen distinctly by the naked Eye, yet with their Light they all combine to illustrate that Region of the Heavens where they are, and diffuse through it a shining Whiteness.

By



By the Help of Images, the antient *Astrono-* Lect. VI.  
*mers* have been able to distinguish and mark out  
 the *Stars* of the Firmament, and with great  
 Care and Industry they have digested them in-  
 to Catalogues, which they have delivered down  
 to Posterity. These Catalogues have been much  
 increased and corrected by our modern *Astrono-*  
*mers*; and now they not only comprehend the  
*Stars* visible by the naked Eye, but also many  
 that are not to be observed or seen without a  
 Telescope.

HIPPARCHUS the *Rhodian* about 120 Years <sup>Hipparchus</sup>  
 before the Birth of *Christ*, was the First among <sup>first compo-</sup>  
 the *Greeks* who reduced the *Stars* into a Cata- <sup>sed a Cata-</sup>  
 logue. *Daring*, according to *Pliny*, to undertake <sup>logue of the</sup>  
 a Thing, which seemed to surpass the Power of <sup>Stars.</sup>  
 a Divinity, that is, to number the *Stars* for Po-  
 sterity, and to reduce them to Rule; having con-  
 trived Instruments by which he marked the Place  
 and Magnitude of each *Star*. So that by this Means  
 we can easily discover, not only whether any of the  
*Stars* perish, and others grow up; but also whether  
 they move, and what is their Course, and also if  
 they grow bigger, or wax less; by which Means he  
 has given to Posterity the Possession of the Heavens,  
 if any of them have Subtilty enough to comprehend  
 them.

HIPPARCHUS from his own proper Observa-  
 tions, and those of the antient *Astronomers* who  
 lived before him, inserted into his Catalogue  
 1022 *Stars*, and annexed to each of them their  
 proper Longitude and Latitude, which they had  
 at that Time. *Ptolemy* enlarged *Hipparchus's*  
 Catalogue only with four *Stars*, numbering  
 1026. And after *Ptolemy*, *Ulug Beighi*, the Grand- <sup>Ulug Beighi</sup>  
 son of the great *Tamerlain*, observed again the <sup>made a new</sup>  
*Stars*, and reduced 1017 of them into a Cata- <sup>Catalogue.</sup>  
 logue. In the 16th Century, and that which  
 followed, *Astronomy* was courted by many Ad-  
 mirers and Suiters; among whom we may chief-  
 ly reckon *Regiomontanus* and *Copernicus*. But  
 the noble *Danish Astronomer Tycho Brahe*, in a- <sup>As likewise</sup>  
 dorning <sup>Tycho</sup> <sup>Brahe.</sup>



Lect. VI. dawning and perfecting this Science, did far surpass the Labours of all that went before him; who procured very large and exquisitely well contrived Instruments for observing the Heavens; and particularly he determined the Places of 777 *fixed Stars*, and reduced them into a Catalogue, their Places being all calculated from his own proper Observations. *Kepler* indeed, in his *Rudolphin* Tables, gives us a Catalogue of the *Stars*, he calls *Tychonick*, in which he has put down 1163 *Stars*; but all of them, except the 777 observed by *Tycho*, were taken partly from *Ptolemy*, and partly from other Authors. For *Tycho* in his own Catalogue sets down no *Star* which he had not observed himself, by his own Instruments, and calculated the Place from his proper Observations.

*The Prince of Hefs.*

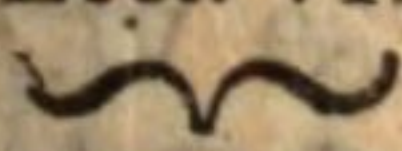
ABOUT the same Time with *Tycho* lived *William Prince of Hefs*, who likewise observed the *Stars*: He had two *Mathematicians* to assist him, *Rothmannus* and *Byrgius*, with whom, by thirty Years continued Labour, he computed the Places of 400 *Stars*, all founded on their own Observations, and inserted them in a Catalogue.

*Ricciolus.*

THE Jesuit *Ricciolus* enriched the Catalogue of *Kepler* with 305 *Stars*, by which Means their Number was increased to 1468; but this Catalogue was not founded on his own Observations; for he, and his Companion *Grimaldi*, did not take the Places of above 101 *Stars* with their own Instruments; and he took all the rest from *Tycho*, *Kepler*, and other Authors: But it is surprising, that *Ricciolus* should insert in his Catalogue several *Stars*, which were plainly visible in *Tycho's* Time, and duly observed by him, but which in *Riccioli's* Days had vanished, and were not to be seen; and yet they are preserved in his Catalogue, as if he himself had then observed them.

*BARTSCHIVS*, in his Book about the four Foot-Globe published at *Strasburgh* in 1635, in 4to, tells us, That *Bayerus* had described in his *Uranometria*, the Places of 1725 *Stars*, and he also



also boasts, that he himself had painted in his Globe Lect. VI. 1762 Stars; but he does not tell us by whom, or  in what Year they were observed.

THE Stars near the *Antarctick Pole*, not to be seen in our Climate, were first accurately observed by my Colleague Dr. *Edmund Halley*; who being ani-<sup>Dr. Halley</sup>mated with a great Love of this Siderial Science,<sup>first exactly</sup> undertook a long, and no less dangerous Voyage to <sup>observed the</sup> Southern the Island of *St. Helena*, that he might there take Stars. the Position of the Stars which are within the *Antarctick Circle*; and he published a Catalogue of 373 of them, whose Places he adapted to the End of the Year 1677.

THE illustrious *John Hevelius* of *Dantzic*, a <sup>Hevelius.</sup> Man of prodigious Industry, and unwearied Diligence, being well furnished with very exact Instruments, and with all the Tools that are proper for an *Astronomer*, did again assault the Stars with his Instruments, and computed the Places of 1553 of them from his own proper Observations; and so he composed a new Catalogue, which contained 1888, viz. 950 known to the Antients, and which were to be seen at *Dantzic*; 603 new ones, which no one before had ever rightly observed; and to them he joined 335 others round the *Antarctick Pole*, taken out of Dr. *Halley's* Catalogue, which lie always hid under the *Horizon* of *Dantzic*.

BUT the largest and most complete Catalogue <sup>Mr. Flam-</sup>of the Stars \* is shortly to be expected from the <sup>steed has</sup> Labours of that most excellent Observer Mr. *John* <sup>made the</sup> *Flamsteed*, late Royal Professor of *Astronomy* at <sup>most copious</sup> *Greenwich*; the Number of Stars inserted in this <sup>and most ex-</sup> Catalogue reach to 3000. And as *Hevelius* dou-<sup>act Cata-</sup>bled by his Observations the Number of Stars <sup>logue.</sup> observed by *Tycho*: So our *British Astronomer* has as far out-done *Hevelius*, having by his Observations doubled the Stars that were observed by him: We are so much indebted to this *Astronomer* for the Increase of the Knowledge we have of the Cele-

\* This Catalogue was published Anno 1725.



Lect. VI. *stial Bodies*, that there is not the least *Star* in the Heavens to be seen, whose Place and Situation is not better known, than the Position of many Cities thro' which Travellers do daily pass. Nor is it any Wonder, that the *Astronomers* should take so much Pains, and so obstinately watch the *fixed Stars*, to determine their Places; for without the exact settling of their Positions and Places, they could never have found out the Ways of the *Planets*, nor have described their Orbits: For it is upon the Observations of the *fixed Stars*, as upon immoveable Pillars, that the whole Science of *Astronomy* is erected, and by them it is sustained.

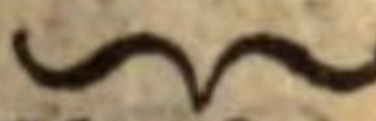
*The Number  
of the Stars.*

OF the 3000 *Stars* inserted in Mr. *Flamsteed's* Catalogue, there are many that cannot be seen without a Telescope; so that it is seldom that even a very good Eye can reckon more than 100 together in the Heavens: This will certainly surprize a great many Persons; for in the Winter, in a clear Night, without *Moon-shine*, at first Sight they seem to be innumerable. But this Appearance is only a Deception of our Sight, arising from their vehement and strong Twinkling, or Scintillation, while we look upon them confusedly, and without reducing them to any Order; but he who will distinctly view them, will find not one but what are observed by the *Astronomers*, and inserted in their Catalogues: And if any one will take a Globe of the larger Size, and compare it with the Heavens; he will rarely find any *Star* in the Heavens, that is not marked upon the Surface of that Globe.

IN the mean Time I must acknowledge, that the Number of the *Stars* is really vastly great, and almost infinite; for whoever will view the *Stars* with a good Telescope, will find every-where a prodigious Number of them altogether indiscernable by the naked Eye, especially in the *Milky-way*; where they are so thick, that tho' they cannot be seen separately, yet they give that Region of the Heavens, where they are placed, a Lustre above all the rest.

THE



THE famous Dr. *Hook*, Professor of *Geometry* in Lect. VI. *Gresham-College*, directing his twelve-foot Telescope  to the *Pleiades* or the seven *Stars*, though there are <sup>Many Stars</sup> now only six to be seen with the naked Eye, did <sup>impercepti-</sup> in that small Compass count 78 *Stars*; and making <sup>ble to the</sup> use of longer and more perfect Telescopes, he discovered a great many more of very different Magnitudes: See his *Micrography*, pag. 241. *Antonius Maria de Reita*, in his Book which he calls *Radius Sidereomysticus*, pag. 197, affirms, that he has numbered in the single Constellation of *Orion* 2000 *Stars*.

FROM what we have said, in the preceding <sup>The Matter</sup> Lecture, it plainly appears, how false and ill-<sup>of the Hea-</sup> founded were the Notions of the antient *Philo-*<sup>vens is cor-</sup> *sophers*, who having too favourable an Opinion of <sup>ruptible and</sup> the Heavenly Regions, granted them some Privileges without any reasonable Ground: For they affirmed, that the Heavens were incapable of any Change, that the Celestial Matter was of a different Kind from any we have in our *Earth*, and that its Firmness did far exceed that of the most durable Diamond; for that is still corruptible, and may be changed into other Sorts of Matter, and undergo several Transmutations: But the Form of the Heavenly Matter, according to them, is permanent and eternal. We have seen in the *Sun* and *Planets*, that there are frequently new Bodies produced and generated; others again are corrupted and perish, and the Faces of the *Planets* undergo many Changes. Those *Alterations* are not peculiar to our *Earth*, or our Planetary System; the Principle of Generation and Corruption is much further diffused, it reaches even the most distant *fixed Stars*, and all the Bodies of the Universe are under its Dominion; there is nothing but our Mind, and our Spiritual Part, that are exempted from its Jurisdiction: For the Heavenly Bodies, as well as the Terrestrial, are changeable and perish. Several *Stars* which were observed by the Antients, are now no more to be seen, but are destroyed, and we have known some new ones



Lect. VI. come in the Heavens unknown to them ; which likewise in due Time will vanish, and disappear.

Some Stars  
vanish or  
perish, and  
again ap-  
pear.

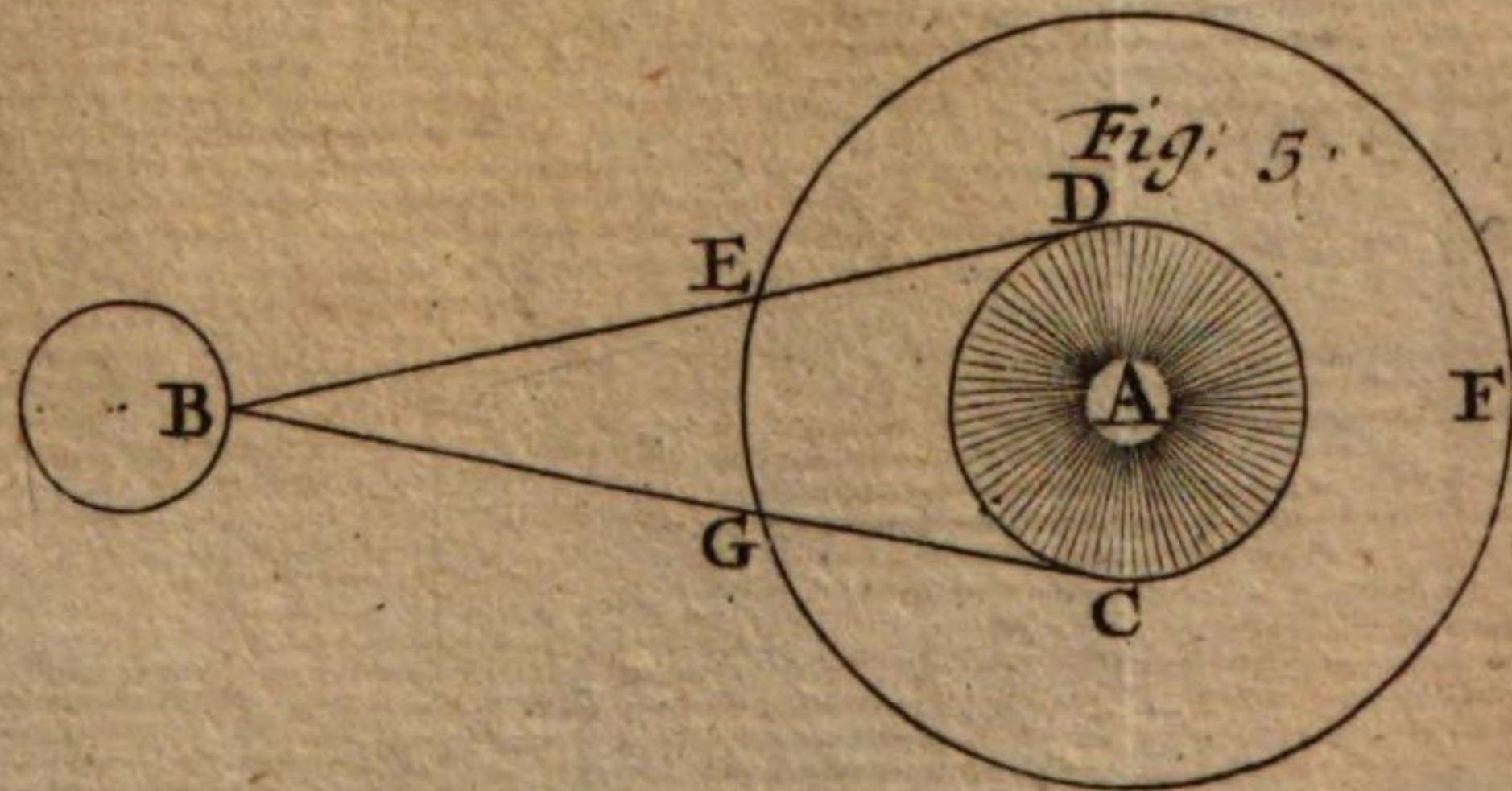
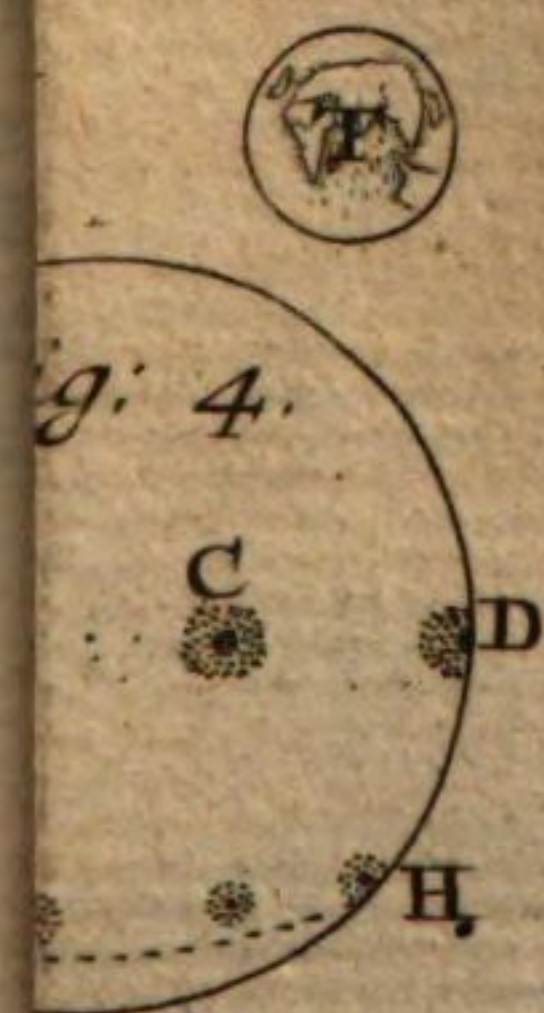
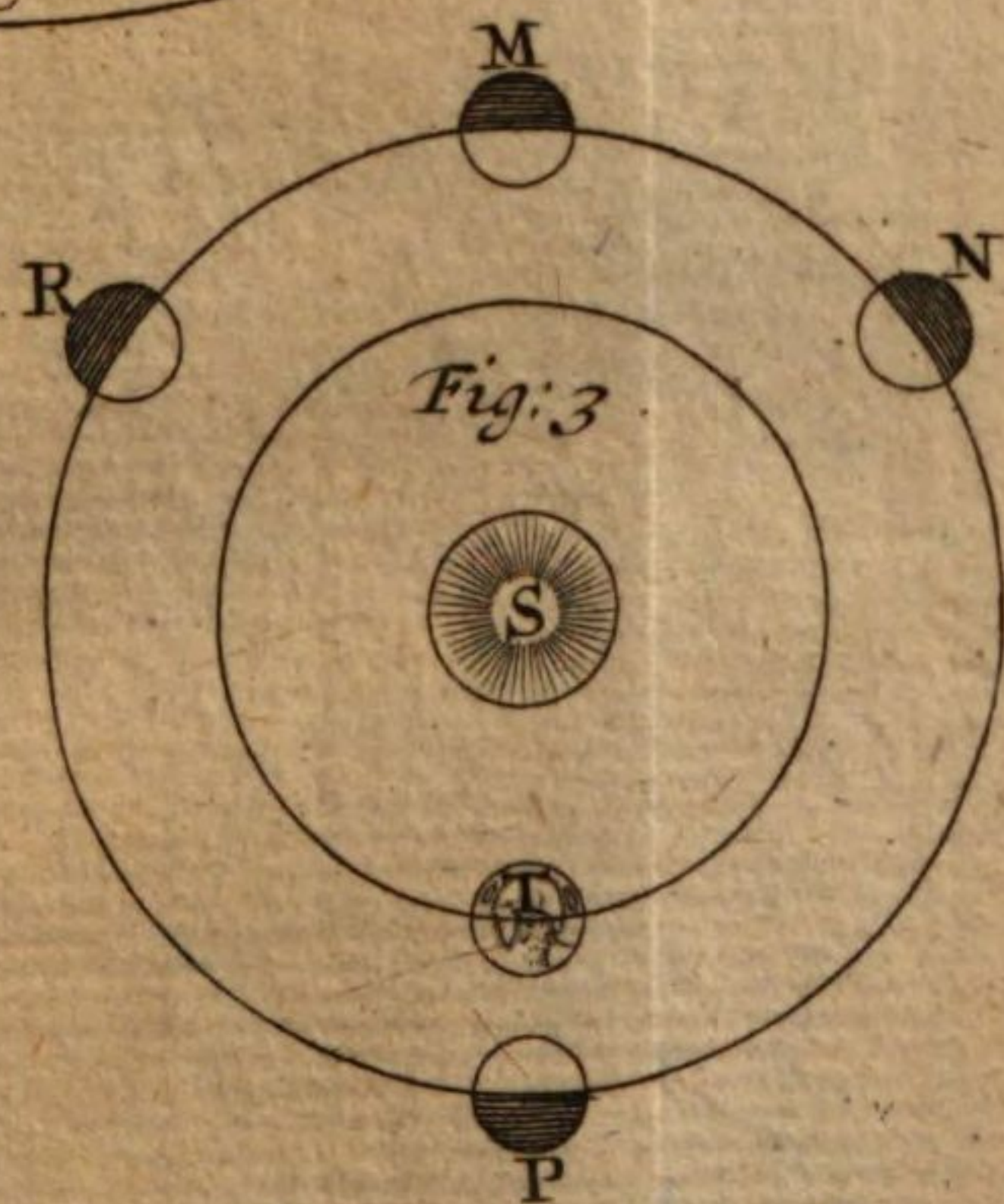
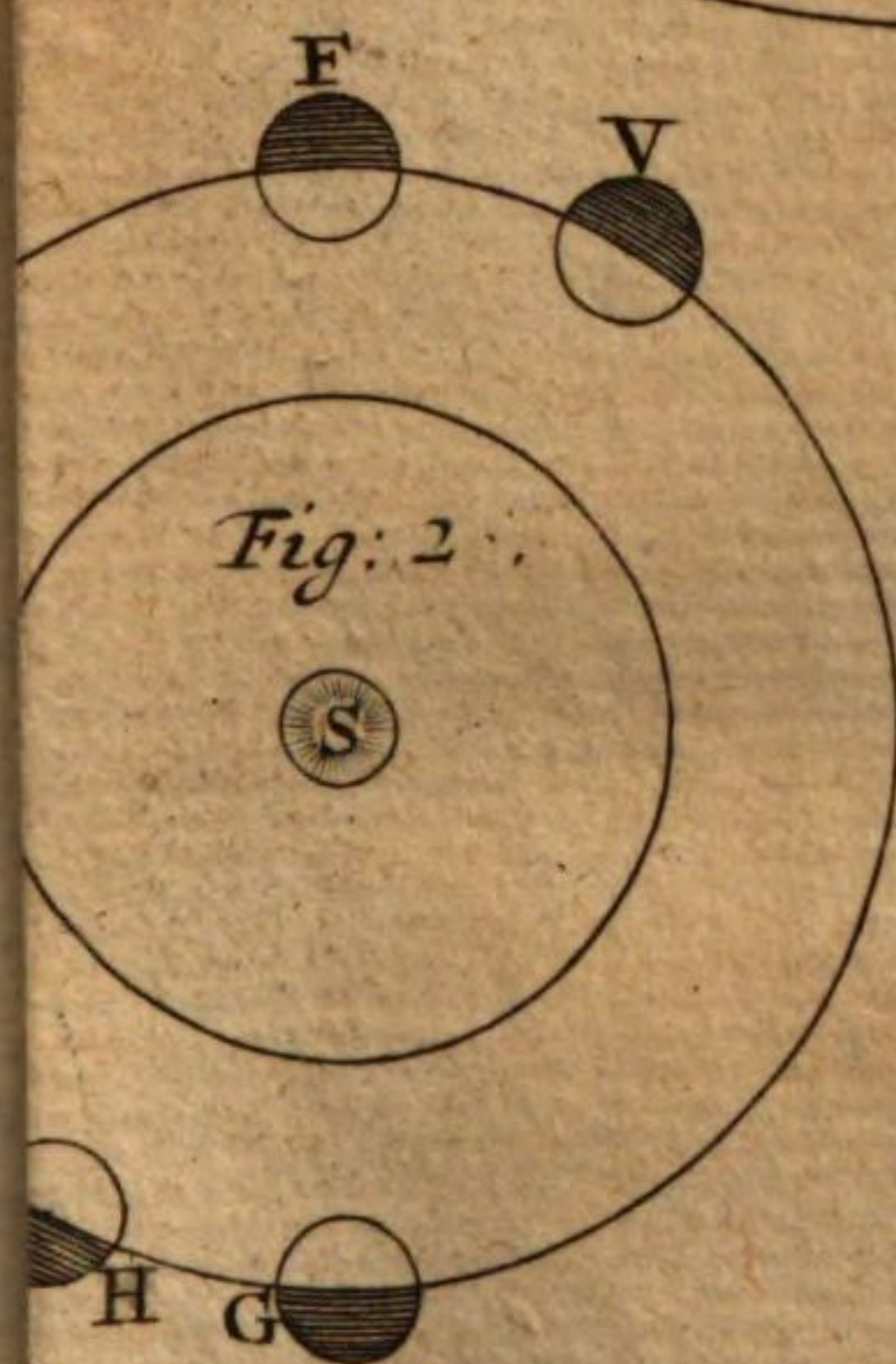
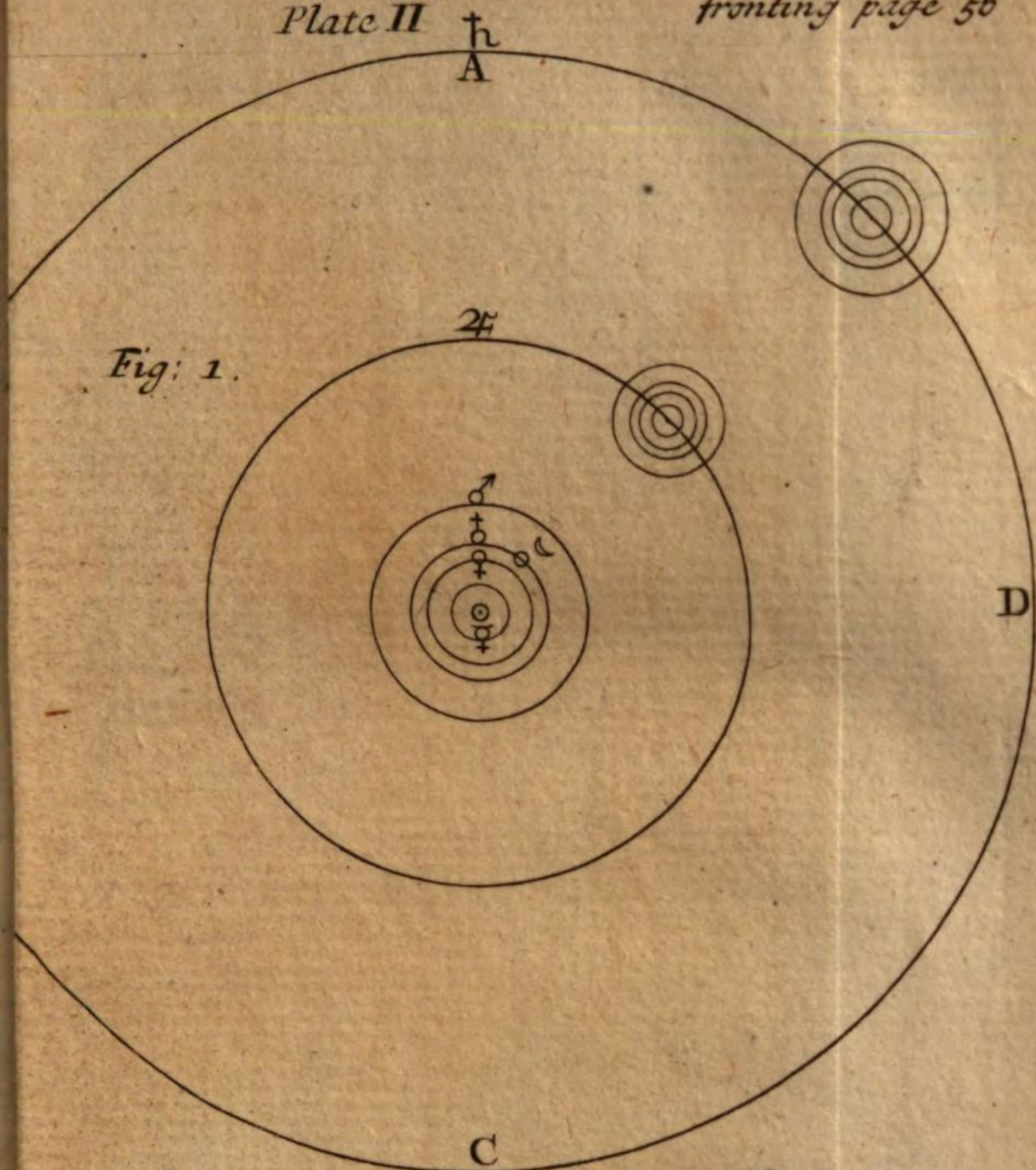
There are also some *Stars* which for a Time are extinguished, and become invisible, but after a certain Period they re-assume their former Lustre. Of these *Stars*, the most remarkable is that which is in the Neck of the *Whale*, which for eight or nine Months of the Year withdraws itself from our Sight, and for the other three or four Months is constantly changing its Lustre and Bigness. It is probable, that the greatest Part of the Surface of this *Star* is covered with Spots and dark Bodies, some Part thereof remaining lucid ; and while it turns about its *Axis*, does sometimes shew its bright Part, sometimes it turns its dark Side to us : But the very Spots themselves of this *Star* are liable to Changes ; for it does not every Year appear with the same Lustre ; sometimes it resembles a *Star* of the second Magnitude, in other Years it can scarcely be reckoned among *Stars* of the third Order : Nor are the Times of its visiting us, always of the same Duration ; for in some Years after three Months it take its Leave of us ; in others we enjoy its Light for the Space of four Months ; nor does its Increase or Decrease always answer the Difference of Times.

New Stars.

MOREOVER we are assured from the Observations of *Astronomers*, that some *Stars* have been observed which never were before, and for a certain Time they have distinguished them by their *superlative Lustre* ; but afterwards decreasing, they by Degrees vanished, and were no more to be seen. One of these *Stars* being first seen and observed by *Hipparchus*, the chief of the *Astronomers* of the Antients, set him upon composing a Catalogue of the *fixed Stars*, that Posterity might by it learn whether any of the *Stars* perish, and others are produced afresh.

AFTER several Ages, another new *Star* appeared to *Tycho*, and the *Astronomers* that were contemporary with him ; which just like the new *Star* in *Hipparchus's* Time, induced him likewise











wife to make a new Catalogue of the *fixed Stars*. Lect. VI. This *Star* made its Appearance in the Constellation *Cassiopeia*, and was first observed about the Middle of *November*, 1572, and never changed its Place all the Time it was visible, which was for the Space of sixteen Months; but yet by Degrees it diminished, and at last became invisible. Its Magnitude exceeded that of *Sirius* or *Lyra*, which are the brightest of the *fixed Stars*, and even vied with *Venus* when she is nearest to us: So that sometimes it could be seen in fair Day-light, or Sun-shine; but at last it continually lost something of its Splendor, 'till it quite disappeared, and it has never been seen since. *Leovicius*, from the Histories of those Times, tells us, that in the Time of the Emperor *Otho*, about the Year 945, a new *Star* appeared in *Cassiopeia*, just such a one as was seen in his Time in the Year 1572. And he brings us another antient Observation, that there was likewise seen in the Northern Region of the Heavens, near the Constellation *Cassiopeia*, in the Year 1264, an eminently bright *Star*, which kept itself in the same Place, and had no proper Motion. It is probable, that these two *Stars* might have been the same with that which was seen by *Tycho*, and that in about 150 Years the same *Star* may again make its Appearance.

IN the Year 1600 and the following, *Kepler* observed another new *Star* in the *Swan's Breast*, which remained visible for many Years; and in *Hevelius's* Time looked like a *Star* of the third Magnitude; but at last became invisible from the Year 1660 till the Year 1666, when it was again observed by *Hevelius* as a *Star* of the sixth Magnitude just in the same Place as it was at first observed in; where it now appears.

WE are assured by the Catalogues of the *fixed Stars*, that many Stars have been observed by the Antients, and some even by *Tycho*, which are now become invisible, and particularly in the *Pleiades* or *seven Stars*; there were formerly counted



Lect. VI. ed seven, but now we can reckon but fix; and so  
 it was in *Ovid's* Time, who in his third Book of  
 the *Fasti*, has this Verse;

*Quæ septem dici, sex tamen esse solent.*

THE celebrated Mr. *Montanere*, Professor of  
*Mathematicks* of the University of *Bononia*, in his  
 Letter written to the ROYAL SOCIETY, dated  
 April 30, 1670, has these Words: "There are  
 " now wanting in the Heavens two *Stars* of  
 " the second Magnitude, in the Stern of the Ship  
 " *Argo*, and its Yard; *Bayerus* marked them with  
 " the Letters  $\beta$  and  $\gamma$ . I and others observed  
 " them in the Year 1664, upon the Occasion of  
 " the Comet that appeared that Year: When  
 " they disappeared first, I know not; only I am  
 " sure, that in the Year 1668, upon the 10th of  
 " April there was not the least Glimpse of them  
 " to be seen; and yet the rest about them, even  
 " of the third and fourth Magnitudes, remained  
 " the same. I have observed many more Changes  
 " among the *fixed Stars*, even to the Number of a  
 " Hundred, though none of them are so great as  
 " those I have shewed."

It is no ways improbable, that these *Stars* lost  
 their Brightness by a prodigious Number of Spots,  
 which intirely cover'd, and, as it were, overwhelm'd  
 them. In what dismal Condition must their *Pla-*  
*nets* remain, who have nothing but the dim and  
 twinkling Rays of the *fixed Stars* to enlighten  
 them?

LECTURE



## LECTURE VII.

*Of the Motion of the Earth round the Sun, and also about her own Axis; whereby the Apparent Motion of the Sun and Heavens are explained.*



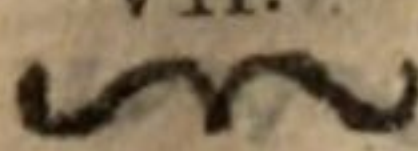
HAVING taken a cursory View of the Universe, and explained those Things which we have discovered concerning the *fixed Stars*, we will now come to consider more accurately our own solar System; for our *Astronomy* is chiefly concerned about the Motions of the Bodies that are contained in it, and about the Appearances or *Phænomena* that arise from those Motions.

AND, first, it is reasonable that we should begin *We are to* from the Motion of the *Earth*, which is our own *begin with* Seat and Habitation, that is, from our own Motion; *the Motion* since we are to be the Spectators of all the Appearances which are here to be explained, and particularly, because from our Motion arises the apparent Motion of the *Sun*, which if not first known, the Appearances and Motions of the *Planets* can neither be explained nor computed. *of the Earth.*

WE have in the preceding Lectures demonstrated, that the *Sun*, which is by far the biggest and most noble Body of the Universe, does possess himself of the Center, from whence he every *The Sun in* Way diffuseth upon all the *Planets* his enlivening Beams and Warmth; and that they, as it *the Center of* were, dance round him at different Distances and Periods. The *Earth* which we inhabit is to be reckoned as one of them, who goes round the *our System.* *Sun* in the Space of a Year; and at the same *The Earth* time *turns round* *the Sun.*



Lecture time turns round her own *Axis* every twenty-four  
VII. Hours. Now, since the Distance of the *fixed*

 *Stars* is immensely great, in Comparison of the Distance of the *Earth* from the *Sun*, the Starry Firmament will have the same Face, and there will be the same Situation, Order, and Magnitude of the *Stars*, whether they be viewed from the *Sun*, or from the *Earth*: But since all distant Bodies appear as if they were in the Heavens, a Spectator in the *Sun* will observe the *Earth* to describe a Circle in the Starry Firmament; and because the Plane of the *Earth's* Orbit passes thro' the *Sun*, the Circle which the *Earth* describes, will appear to be a great Circle in the Heavens.

The same Order and Position of the Stars is seen from the Sun and Earth.

The Motion of the Earth seen from the Sun.  
Plate III.  
Fig. 1.

LET *S* represent the *Sun*, *ABCD* the Orbit of the *Earth*, in which the *Earth* is carried from the *West* to the *East* in the Compass of a Year. A Spectator in *S* looking upon the *Earth* at *A*, will refer it to the Star  $\Upsilon$ , as if it were in the same Point of Space with that *Star*: But when the *Earth* is brought to *B*, the Spectator in *S* will see the *Earth* in the Heavens just by the Star  $\Theta$ ; when the *Earth* is gone forward to *C*, it will be seen from the *Sun* in  $\Xi$ ; and when it is come to *D*, it will appear in  $\Psi$ ; and when it is returned to *A*, having finished its Period, it will be seen again in  $\Upsilon$ .

The Ecliptick and its Division into 12 Parts or Signs.

HENCE, if the Plane of the *Earth's* Orbit be imagined extended to the Heavens, as far as the *fixed Stars*, it will cut the starry Firmament, or the concave spherical Surface, in which all the *Stars* appear, in that very Circle in which a Spectator in the *Sun* would see the *Earth* to revolve every Year: This Circle is called the *Ecliptick*, and divided by the *Astronomers* into twelve equal Parts, which are called Signs; each of them takes its Name from that Constellation, which, at the Time the Names were imposed, was situated near the Portion of the *Ecliptick* it denominates. These Signs or Portions are the *Ram*  $\Upsilon$ , the *Bull*  $\Theta$ , the *Twins*  $\Xi$ , the *Crab*  $\Psi$ , the *Lion*  $\Omega$ , the *Virgin*  $\Upsilon$ , the *Balance*  $\Xi$ , the *Scorpion*



pion ♄, the Archer ♐, the Goat ♈, the Water-Bearer ♒, and the Fishes ♓. Lecture VII.

LET us now bring our Spectator from the *Sun* to the *Earth*, and let him be carried by it round the *Sun*, and let us imagine that the *Earth* is in C: A Spectator sees the same Face of the Heavens, and the very same Constellations, as we have said he did before, while he was in the *Sun*; the only Difference will be, that, as before he imagined the *Earth* in the Heavens, and the *Sun* in the Center, he will now suppose the *Sun* to be in the Heavens, and himself with the *Earth* in the Center, it being really the Center of his own View. Therefore the *Earth* being in C, the Spectator will see the *Sun* at the Star  $\gamma$ ; and the Spectator being carried along with the *Earth*, and participating of the annual Motion, which is common to them both, he will observe all the Parts of the *Earth*, and all the Bodies fixed on its Surface, to keep the same Position in regard to one another, and to his own Eye, and always to remain at the same Distance from him; and therefore he cannot by his Eye, perceive either his own Motion, or that of the *Earth*. But looking to the *Sun*, and observing him, when the *Earth* comes to D, he will see the *Sun* at the Star  $\delta$ , and will perceive that he has changed his Place among the Stars, and has moved from  $\gamma$ , by  $\zeta$ ,  $\eta$ , to  $\delta$ : And while the *Earth* goes on in its Progress, and goes to A, the *Sun* will be seen from thence to have moved through the Signs  $\phi$ ,  $\chi$ , and  $\psi$ : And again, while the *Earth* describes the Semi-circle ABC, the *Sun* will appear to have moved, in the concave Surface of the Heavens, through the six Signs  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ ,  $\epsilon$ ,  $\zeta$ . And therefore an Inhabitant of the *Earth* observes the *Sun*, which is really immoveable, to go through the same Circle in the Heavens, and in the same Space of Time, that a Spectator in the *Sun*, would see the *Earth* describe.

HENCE



Lecture  
VII.



HENCE arises the apparent Motion of the *Sun*, by which it is observed to creep every Day by little and little towards the *Eastern Stars*; so that if any *Star* near the *Ecliptick* does at any Time rise with the *Sun*, after some few Days the *Sun* will be got more to the *East* of the *Star*, and the *Star* will rise before the *Sun*, and will likewise set before him. So likewise a *Star* which is *Eastward* of the *Sun*, and is seen after the *Sun* sets, at a considerable Distance from him, in the Space of some few Days will set with the *Sun*, and will no more be seen after the *Sun* goes down. This Motion of the *Sun*, which is contrary to the apparent diurnal Revolution of the Heavens from *East* to *West*, was esteemed to be real by the Followers of *Ptolemy*, who maintained, that the *Sun* and all the *Stars* had two Motions, contrary to one another, the one common with the Heavens from *East* to *West*, in the Space of 24 Hours; the other proper, and peculiar to each, and was from the *West* to the *East*; which Course the *Sun* finished in the Space of a Year. But we have shewed, that there is no such real Motion in the *Sun*, and that it is only apparent, arising from the Motion of the *Earth*.

The *Sun* will  
have just such  
Motions,  
when it is  
observed  
from other  
Planets.

THE Inhabitants of all the other *Planets* will observe just such Motions in the *Sun*, and for the very same Reasons that we do in our *Earth*: And the *Sun* will be seen from every *Planet*, to describe the same Circle, and in the same Space of Time that a Spectator in the *Sun* would observe the *Planet* to do. For Example: An Inhabitant of *Jupiter* would think that the *Sun* turns round him, and would see him describe a Circle in the Heavens in the Space of twelve Years; that Circle would not be the same with our *Ecliptick*, and the Motion of the *Sun* would not be thro' the same *Stars*, which he appears to us to pass by. And upon the same Account the *Sun* seen from *Saturn* will appear to move in another Circle, distinct from either of the former, and will not seem to finish his Period in less Time than



than 30 Years. Since therefore it is impossible that the *Sun* can have all these Motions really in itself, and there can be no Reason shewn, why any one of them should belong really to the *Sun* more than the rest, we may safely affirm that there are none of them real, but that they are all apparent, and arise from the Motions of the respective *Planets*. Lecture VII.

BESIDES this annual Circulation of the *Earth*, it has also a *vertiginous Motion* round its *Axis*, from the *West* to the *East*, in twenty-four Hours: The two Points in which the *Axis* meets with the Surface of the *Earth*, are called the *Poles* of the *Earth*; and if this *Axis* be indefinitely produced to the Heavens both Ways, it will mark in the Heavens two Points, which are called the *Poles* of the Heavens: Every Point on the Surface of the *Earth*, except the *Poles*, will describe the Circumference of a Circle bigger or less, according as it is further distant or nearer to one of the *Poles*. The *Poles* are the only two Points which have no Verticity: This plainly follows for the Nature of a vertiginous Motion. Any Place on the Surface of the *Earth*, which is equally distant from both the *Poles*, describes by its Rotation a great Circle, which is called the *Æquator* of the *Earth*, or the *Æquinottial Circle*; and the rest described by Points nearer to one of the *Poles*, are lesser Circles, and are called *Parallels*. *The Gyration of the Earth round its Axis.*  
*The Poles.*  
*The Æquator, or Æquinottial and Parallels.*

IF we imagine a Plane to pass over that Point of the *Earth's* Surface on which the Spectator stands, and to touch the Globe of the *Earth* there; this Plane, extended as far as the Heavens, will divide the Heavens into two Parts, and its Section with the Heavens will make a Circle, which is called the *Horizon*; and it will separate or distinguish the visible and open Part of the Heavens, from that which is invisible, and which the Opakeness and Convexity of the Earth hides from us. This *Horizon* which we have described is properly the *Sensible Horizon*: The Rational *Horizon*. *The Horizon.*  
*Plate III.*  
*Fig. 2.*  
*The Sensible and Rational Horizon.*



Lecture  
VII.

*Horizon* being a distinct Circle which passes thro' the Center of the *Earth*, and is parallel to the Sensible which touches the Surface. But these two Circles, tho' they are distant from one another by the Semidiameter of the *Earth*, yet in the Heavens they may be reckoned as coinciding; for that Semidiameter is but a Point, in Comparison of the Distance of the Heavens.

*The Rotation of the Earth produces an apparent Revolution of the Heavens round the Earth.*

SINCE the *Earth* turns round its *Axis*, the Spectator, standing on its Surface, must likewise turn round with it the same Way, that is, towards the *East*: And therefore all the Bodies in the Heavens, which are placed in the *East*, and were not to be seen by Reason the Plane of the *Horizon* was above them, will become visible, when by the Rotation this Plane subsides, and comes under them. So likewise the opposite Part of this Plane towards the *West*, rising above the *Stars*, will hide them from the Sight of the Spectator, and all the *Stars* in the *West* will become invisible. Hence it is, the *Stars* of the *Eastern* Side of the *Horizon* will appear to rise above the *Horizon*, because the *Horizon* descends below them; and the *Stars* on the *Western* Side will appear to set, or go below the *Horizon*, because the *Horizon* does really get above them. Hence arises that apparent Motion of all the Bodies of the Universe that do not adhere to the *Earth*, wherewith the whole starry Firmament, and every Point of the Heavens seem to revolve about the *Earth* from *East* to *West*; every Point describing a greater or lesser Circle, as it is more remote, or nearer to one of the Celestial *Poles*: And these Celestial *Poles* which are made by the Production of the *Earth's Axis* to the Heavens, are the only Points in the Heavens, which appear to be immoveable.

ALTHO' every Place on the Surface of the terraqueous Globe, is illustrated by all the *Stars* which are above the *Horizon* of that Place, or rather when the *Horizon* is under the *Stars*; yet the Illumination made by the *Sun* is so great, and



and the Reflection of its Light by the Atmosphere so strong, that the *Sun*, when he is above the *Horizon*, does with his Presence quite extinguish the faint Light of the *fixed Stars*, and produces Day: When the *Sun* withdraws himself, and goes below our *Horizon*, or, more properly, when our *Horizon* gets above the *Sun*, he then gives Leave to the *Stars* to shine and appear, at which Time it is Night. Now since the *Earth* is an opaque spherical Body, at a great Distance from the *Sun*, one Half of it will always be illuminated by the *Sun*, while the other Half remains in Darkness: And the Circle which distinguishes the illuminated Face of the *Earth* from the dark Side, is called the Circle of the Intersection of Light and Shadow; a Line drawn from the Center of the *Sun*, to the Center of the *Earth*, is always perpendicular to the Plane of this Circle.

Lecture VII.

Whence Day-light.

Whence Night.

The Circle bounding Light and Darkness.

IF the *Axis* of the *Earth* had been placed in a Position perpendicular to the Plane of the *Ecliptick*, then in that Case the Plane of the *Earth's* *Æquator* had coincided with the Plane of the *Ecliptick*, or the Plane of the *Earth's* Orbit; and the Circle bounding Light and Darkness, would have always passed thro' the *Poles* of the *Earth*, and cut the *Æquator* and all its *Parallels* into equal Portions: And therefore, in that Case, the *Sun* and all the *Stars* would have remained as long above the *Horizon*, as they would have lain hid under it, and the Days would have been constantly equal to the Nights. But now as the Case is, the *Axis* of the *Earth* is not perpendicular to the Plane of the *Ecliptick*, but is inclined to that Plane, and makes with it an Angle of  $66\frac{1}{2}$  Degrees; and therefore the Plane of the *Earth's* *Æquator* cannot coincide with the Plane of the *Ecliptick*, but these two Planes make with one another an Angle of  $23\frac{1}{2}$  Degrees.

The Axis of the Earth is not perpendicular to the Plane of the Ecliptick.

IF the Plane of the *Earth's* *Æquator* be imagined to be produced as far as the *fixed Stars*, it will there make a Circle which is called the Celestial *Æquinoctial*; which is exactly over the

The Æquinoctial of the Heavens.

F

Terre-



Lecture VII. Terrestrial *Æ*quinoctial: This Circle makes with the Ecliptick in the Heavens, an Angle likewise of  $23\frac{1}{2}$  Degrees.

*The Parallelism of the Earth's Axis.*

Plate III.  
Fig. 3.

THE *Earth* in its Revolution round the *Sun* does in such a Manner proceed in its Orbit, that it keeps its *Axis* parallel to itself; that is, if a Line be drawn parallel to the *Axis* while it is in any one Position, the *Axis* in all other Positions or Parts of the Orbit will always be parallel to that same Line, and it will never change its Direction, but always look towards the same Point of the Heavens: And this will necessarily be, if the *Earth* have no other Motion but that round the *Sun*, and the other round its own *Axis*. For suppose any Body, whose Center is carried in the Line *AB*, and in *A* we should mark any Diameter *CD*, which is inclined in any Angle to the Line *AB*; if this Body have no other but a progressive Motion in the Line *AB*, when it comes to the Point *B*, the Diameter *CD* will be in the Situation *cd*, and its Position will be parallel to the former Position *CD*: Now if there should be impressed upon this Body a Rotation round *CD* as an *Axis*, all the Diameters of the Body will constantly change their Position by this Rotation, except the *Axis*, which will remain in its former State: The Points in the *Axis* being the only Points in the Body which have no Rotation. But this *Axis*, as was shewed, did before the Rotation always preserve a Position parallel to itself; therefore after the Rotation is impressed upon the Body, the *Axis* will still keep parallel to itself.

HENCE it is evident, that there is no need of a third Motion for the *Earth*, as some have imagined it must have, to make it keep its *Axis* parallel to itself: For to this Effect there is nothing more required, than that it should have only the former two, with which alone it will necessarily keep its *Axis* parallel to itself.

SINCE



SINCE the Plane of the *Æquator* does not coincide with the Plane of the *Ecliptick*, these two Planes must cut one another in a right Line; and while the *Earth* turns round the *Sun*, the common Section of these two Planes will likewise always remain parallel to itself, for the same Reason, as we shewed in the Position of the *Earth's Axis*: And therefore this Section or Line, in which the Planes cut one another, will always be directed towards two opposite Points of the *Ecliptick*, and will always look to the same Points of the Universe.

A great Circle in the Heavens passing thro' the two Celestial Poles, and the common Section of the *Æquator* and the *Ecliptick*, is called the *Equinoctial Colure*: Another Circle, cutting the former in the Poles at right Angles, is called the *Solstitial Colure*, which passes thro' the Points where the *Æquator* and *Ecliptick* are at the greatest Distance from one another, and cuts likewise both these Circles at right Angles; and therefore does likewise pass thro' the Poles of the *Ecliptick*, or that Point which is every-where equally distant from the *Ecliptick*. The four Points in which these two *Colures* intersect the *Ecliptick*, are called the four *Cardinal Points*; because when the *Sun* is seen in them, he determines the four Seasons of the Year. The two Intersections of the *Equinoctial Colure* with the *Ecliptick*, are called the *Equinoctial Points*; the other two, being the Intersections of the *Solstitial Colure* with the *Ecliptick*, are called the *Solstitial Points*.

SUPPOSE now the Eye of a Spectator to look from afar, obliquely upon the Orbit of the *Earth*; it will then appear, or have a Representation of an Oval Figure, according to the Rules of Perspective; and in the middle of this Oval the *Sun* will keep. Thro' the Center of the *Sun* S, draw the right Line  $\gamma S$  parallel to the common Section of the *Æquator* and the *Ecliptick*, which will meet with the *Ecliptick* in two Points  $\gamma, \epsilon$ : And when the *Earth* seen from the *Sun* is in either



Lecture  
VII.

*The different  
Illumination  
of the Pa-  
rallels, ac-  
cording to  
the Place of  
the Earth in  
the Eclip-  
tick.*

*The Ap-  
pearances  
when the  
Earth is in  
Libra, and  
the Sun is  
seen in Aries.*

of these Points, the right Line  $S \gamma$  or  $S \simeq$ , which joins the Center of the *Earth* and *Sun*, will coincide with the common Section of the *Æquator* and *Ecliptick*; and will then be perpendicular to the *Axis* of the *Earth*, or of the *Æquator*, because it is in the Plane of the *Æquator*: But the same Line is also perpendicular to the Circle which bounds the Light and Darknes; and therefore the *Axis* of the *Earth* will be in the Plane of that Circle, which will therefore pass thro' the *Poles* of the *Earth*, and will cut the *Æquator* and all its *Parallels* into equal Parts. When the *Earth* therefore is in the Beginning of  $\simeq$ , the *Sun* will be seen in  $\gamma$ , in the common Section of the *Æquator* and the *Ecliptick*; and therefore it will appear in the Celestial *Æquinoctial*, and will not be seen to decline to either of the *Poles*; but being exactly in the Middle between both, it will then by its apparent diurnal Revolution describe the Celestial *Æquinoctial*. In this Position of the *Earth*, the *Sun* will exactly illuminate the *Earth* from *Pole* to *Pole*; and, as we said, the Circle bounding Light and Darknes will cut the *Parallels* exactly into equal Parts; and every Point of the *Earth*, being carried round by the vertiginous Motion, will remain as long in the obscure Side, as it was in the Light or illuminated Portion of the *Earth's* Surface: And therefore at that Time, thro' the whole Globe of the *Earth*, the Day will be equal to the Night: From hence the Circle which that Day the *Sun* seems to describe in the Heavens, has obtained the Name of *Æquinoctial*.

*The Ap-  
pearances  
when the  
Earth is in  
Capricorn.*

THE *Earth* in its annual Motion going by Degrees thro'  $\mathfrak{M}$  and  $\mathfrak{P}$  towards  $\mathfrak{V}$ , and the common Section of the *Æquator* and the *Ecliptick* remaining always parallel to itself, it will no longer pass through the Body of the *Sun*; but in  $\mathfrak{V}$  it makes a right Angle with the Line  $SP$ , which joins the Centers of the *Sun* and *Earth*: And because the Line  $SP$  is not in the Plane of the *Æquator*, but in that of the *Ecliptick*; the Angle  $BPS$ , which

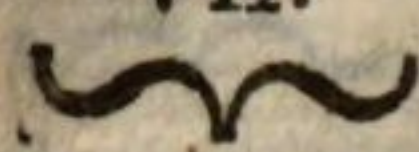


which the *Axis* of the *Earth* makes with it, will not now be a right Angle, but oblique; these two Lines making an Angle of  $66\frac{1}{2}$  Degrees, which is the same with the Inclination of the *Axis* to the Plane of the *Ecliptick*. Let the Angle *SP L* be a right Angle, and the Circle bounding Light and Darkness will pass thro' the Point *L*; and then the Arch *B L*, or the Angle *B P L*, will be  $23\frac{1}{2}$  Degrees, that is, equal to the Complement of the Angle *B P S* to a right Angle.

LET the Angle *B P E* be a right Angle, and then the Line *P E* will be in the Plane of the *Æquator*: Therefore because the Arches *B E* and *L T* are equal, each of them being Quadrants; if the common Arch *B T* be taken away, there will remain *T E* equal to *L B* equal to  $23\frac{1}{2}$  Degrees. Take *E M* equal to *E T*, and thro' the Points *M* and *T*, describe two parallel Circles *T C*, *M N*; the one is called the *Tropick* of *Cancer* ☊; the other the *Tropick* of *Capricorn* ☋. And the *Earth* being in this Situation, the *Sun* will shine perpendicularly upon the Point *T*, and then it will seem to approach the nearest that it can come to the *North Pole*: And the Circle, which by the apparent diurnal Revolution of the Heavens, the *Sun* seems to describe, will be directly over the Circle *T C* in the *Earth*, which Circle is therefore called the *Celestial Tropick* of *Cancer*. Now upon the Account of the Revolution of the *Earth* round its fixed *Axis*, all the Points of the Parallel *T C* will in their Turns pass by the Point *T*, and will be directly under the *Sun*; and therefore the *Sun* will be vertical to all the Inhabitants that are under the *Tropick* of ☊, when he comes to their Meridians. While the *Earth* is in this Position, it is manifest, that the Circle which bounds Light and Darkness reaches beyond the *North Pole* *B* to *L*; but towards the *South* it falls short of the *South Pole* *A*, and reaches no further than *F*. Thro' *L* and *F* let two Parallels to the *Æquator* be described:



Lecture described : These two Circles are called the *Polar*  
 VII. *Circles* ; this is called the *Arctick Polar*, the other

 the *Antarctick*. And while the *Earth* is in P, all that Tract of it which is included within the *Polar* Circle K L, continues in the Light, notwithstanding the constant Revolution round the *Axis* ; and the Inhabitants there enjoy a continual Day. On the contrary, those that lie within the *Antarctick* Circle remain in continual Darknefs, having all Night without any Day. Besides it is likewise manifest, that all the Parallels between the *Æquator* and the *Arctick* Circle, are cut by the Circle bounding Light and Darknefs, into unequal Portions ; the largest Portions of these Circles remaining in the Light, and the smallest in Darknefs : But those Parallels which are towards the *Antarctick* Circle, have their greatest Portions in Darknefs, and the least in the Light ; and the Difference of these Portions will be greater or less, according as the Circles are nearer to the *Pole*, or to the *Æquator*. Therefore in this Position of the *Earth*, when the *Sun* is seen in S, the Inhabitants of the *Northern Hemisphere* will have their Days at the longest, and their Nights the shortest ; and the Season of the Year will be Summer : But in the *Southern Hemisphere* the Inhabitants will have their Nights longest, and their Days shortest ; and they will be in their Winter Season.

The Arc-  
 tick and  
 Antarctick  
 Circles.

When the  
 Days are  
 longest.  
 When short-  
 est.

AND in every Place the Length of the longest Days will be the greatest, and the Nights the shortest, according as the Place is further removed from the *Æquator*, and comes nearer the *North Pole*. We see likewise, that of all the Parallels, there is only the *Æquator* which is cut into equal Parts by the Circle bounding Light and Darknefs, they being both of them great Circles : And therefore it is only the Inhabitants of the *Earth* that live in the *Æquator*, that have their Days constantly equal to their Nights, throughout the whole Year.

WHILE



WHILE the *Earth* goes on from ♍ by ♎, ♏, ♐, ♑, ♒, ♓, to ♈, in which Time the *Sun* is seen to pass thro' the Signs ♈, ♉ and ♊, he will appear to return by little and little towards the *Æquator*; and when the *Earth* is arrived at ♈, the *Sun* will appear in ♈, where the common Section of the *Æquator* and the *Ecliptick* always keeping parallel to itself, will pass thro' the Center of the *Sun*; and then the *Sun* will appear in the Celestial *Æquinoctial*: At which Time the Days will again be equal to the Nights, to all the Inhabitants of the *Earth*; just after the same Way as it was when the *Earth* was in ♈, in that Position the Circle bounding Light and Darkness passing thro' the *Poles*.

The Appearances when the Earth is in Aries.

THE *Earth* moving on thro' ♈, ♉ and ♊, the *Sun* will be seen to go in the *Ecliptick* thro' ♈, ♉ and ♊, and will appear to decline from the *Æquator* towards the *South*; so that when the *Earth* is really in ♈, the *Sun* will appear among the *Stars* near the Constellation ♈. And whereas the *Axis* BA does not change its Inclination, but does always retain its Parallelism, the *Earth* will have the same Aspect and Position in respect to the *Sun*, that it had when it was in ♈; but with this Difference, that when the Tract within the *Polar Circle* KL was in continual Light while the *Earth* was in ♈; now the *Earth* arriving at ♈, that same Tract will be altogether in Darkness, and the Beams of the *Sun* cannot reach it. But the opposite Space within the Circle FG, will be in a continual Illumination, and at the Pole A there will be no Night for the Space of six Months.

The Appearances when the Earth is in Cancer.

HERE likewise of the Parallels between the *Æquator* and the *North Pole*, the illuminated Portions are much less than the Portions which remain in Darkness; the contrary of which happened in the former Position. So likewise the *Sun* at Mid-day will appear vertical,



Lecture or directly over Head to all the Inhabitants that  
 VII. live in the Tropick MN, so that it will appear  
 to have descended towards the *South* from the  
 Parallel TC to the Parallel MN, through the  
 Arch CQN, which is 47 Degrees. Therefore  
 the Inhabitants of all Places of the *Earth* that  
 are beyond the Tropicks, towards either of the  
*Poles*, have the *Sun* in their Summer 47 whole  
 Degrees nearer to their Vertex, or to the Point  
 directly over their Heads, than in the opposite  
 Time of Winter. This Change of Situation in  
 respect to the *Sun*, does not arise because the  
*Earth* is raised or depressed, but on the con-  
 trary, because it is no-where depressed, and no-  
 where raised; but with its *Axis* keeps the same  
 immutable Position, in respect of the Universe,  
 only going round the *Sun* which is placed in the  
 Center of its Orbit, and the *Axis* thereof retaining  
 the same Inclination to the Plane of the Orbit, and  
 the same Situation in respect to any other fixed  
 Line.

How all  
 these Ap-  
 pearances  
 may be re-  
 presented to  
 the Eye.

ALL we have here said will appear evident  
 to our Eyes, if we light a Candle in a dark  
 Room, and take a small Globe of two or three  
 Inches Diameter, in which we must mark the  
*Poles*, the *Æquator*, some *Parallels*, and some  
*Meridians*, or *Circles* passing from *Pole* to *Pole*;  
 Then we must so hold this Globe before the  
 Candle, that its *Axis* may not be perpendi-  
 cular to the Plane of the Table on which the  
 Candle stands; but let it be inclined to it,  
 in an Angle nearly of  $66\frac{1}{2}$  Degrees: Then place  
 the Globe in such a Manner, that one of its  
*Poles* may point directly *Northward*; and let  
 the Light of the Candle first reach from *Pole*  
 to *Pole*; that is, let the Circle bounding Light  
 and Shadow first pass thro' the two *Poles*  
 of the Globe: Then let the Position of the  
*Axis* be well observed, and then move the  
 Globe round the Candle with your Hand, in  
 a Circle parallel to the *Horizon*, holding it so  
 that



that the *Axis* may always point the same Way, and retain the same Inclination to the *Horizon*. This done, you will see that the Flame of the Candle will in the same Manner illuminate this Globe, as the *Sun* actually does the *Earth*: And the *Poles* of the Globe, its *Æquator* and *Parallels*, will undergo the same Vicissitudes of Light and Darkeness, which we have now explained.

THE like *Phænomena* or Appearances may be observed from any other *Planet* that turns round its *Axis*. For Example: *Jupiter* performs his Gyration in the Space of ten Hours; and therefore a *Jovian*, or an Inhabitant of *Jupiter*, will see the whole Heavens, and even our *Earth* together with the *Sun*, to have a rapid Motion round his Body in the Space of ten Hours: But the *Axis* of *Jupiter* is very nearly perpendicular to the Plane of his Orbit, and therefore the Circle bounding Light and Darkeness in *Jupiter*, does always nearly pass through his *Poles*; and therefore the Days and Nights in that *Planet* are almost constantly equal. Hence it seems the *Jovians* enjoy an uniform temperate Season, without being uneasy at the approaching Heats of the Summer, or the Colds of the Winter.

IF through the Center of the *Sun* or *Earth* (it is no matter which, for these two Points at the Distance of the *Stars* will be seen to coincide) there be raised a Line which is perpendicular to the Plane of the *Ecliptick*, and this Line be produced to the Heavens, it is called the *Axis* of the *Ecliptick*; and the two Points which this Line on both Sides produced, does tend to in the Heavens, are called the *Poles* of the Heavens. Now if we imagine great Circles to pass through these *Poles*, and by every *Star* or *Planet*, they will all be perpendicular to the Plane of the *Ecliptick*. These Circles are called *Secondaries* of the *Ecliptick*, or *Circles of Longitude*. And an Arch of one of these Circles intercepted between any *Star* and the *Ecliptick* is called the *Latitude* of that *Star*, or its Distance from the *Ecliptick*; which may be either North



Lecture VII. *North or South*, according as the *Star* is upon the *North or South Side* of the *Ecliptick*. So also an Arch of the *Ecliptick* between the first Point of  $\gamma$ , or its Intersection there with the *Æquator*, and the Point where the Circle of Longitude passing thro' a *Star*, cuts the *Ecliptick*, is called the *Longitude* of that *Star*.

The Longitude of a Star.

The Meridians.

The Latitude of a Place.

Its Longitude.

AFTER the same Manner if there be conceived innumerable Circles to pass through the two *Poles* of the *Earth*, and through each Place on its Surface, they will all be perpendicular to the *Æquator*, and they are called *Secondaries* of the *Æquator*: But in respect of the Places through which they pass, they are called *Meridians*; because when the Sun is seen in any Place, in the Plane of such Circle, it will be Mid-Day to the Inhabitants of that Place. The Arch of one of these *Secondaries* intercepted between any Place and the *Æquator*, is called the *Latitude* of the Place, or its Distance from the *Æquator*, which may be likewise either *North* or *South*: And that Arch of the *Æquator*, that lies between the Intersection of the secondary passing through any Place, with the *Æquator*, and any other fixed Point in the *Æquator*, is called the *Longitude* of that Place.

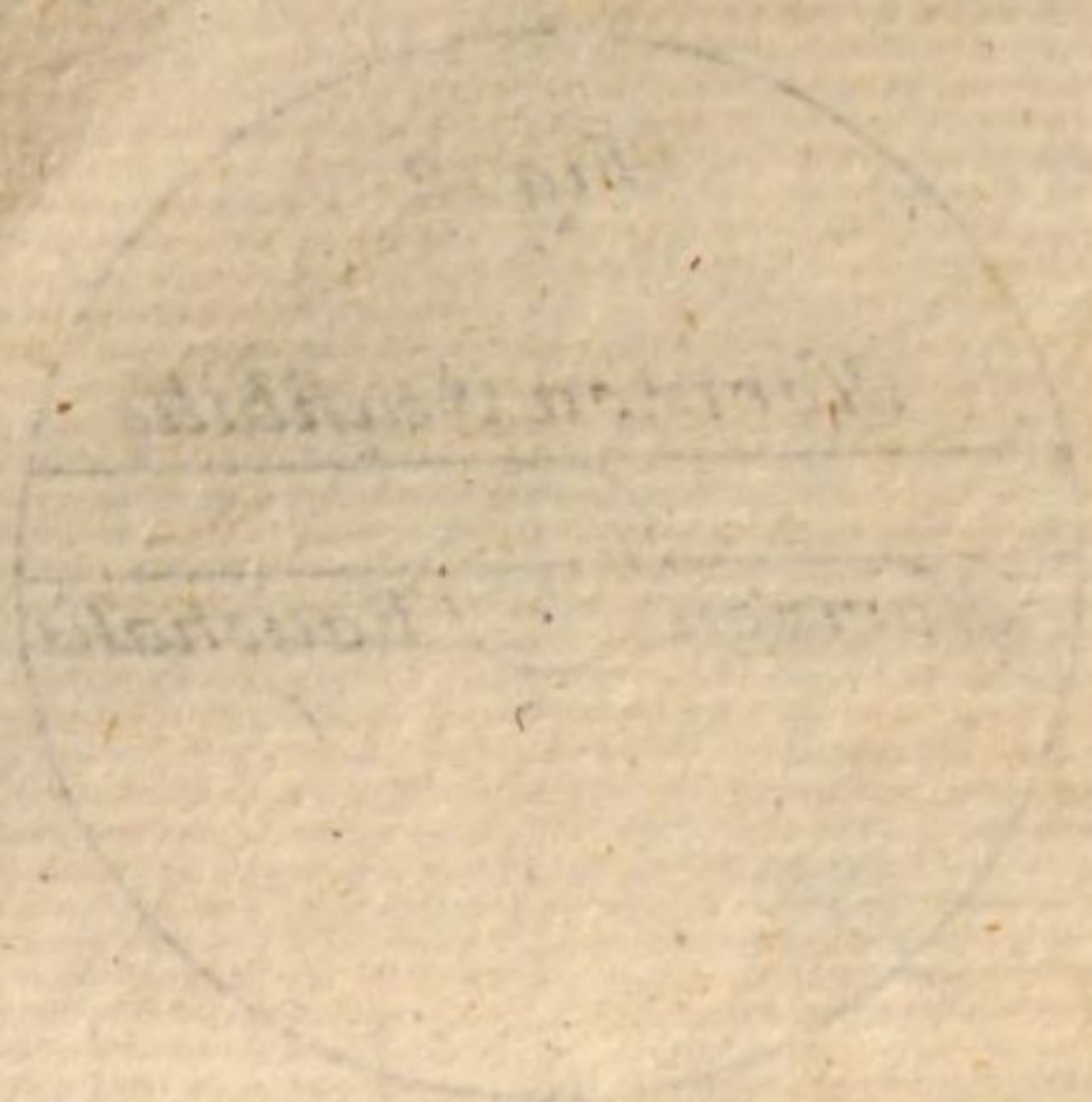


LECTURE





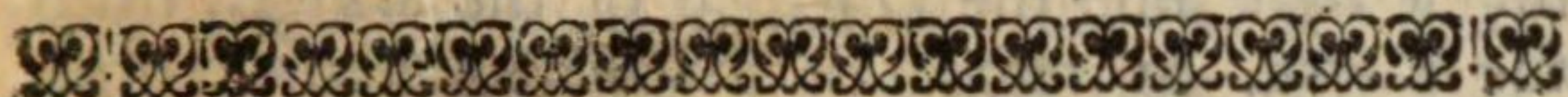




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## LECTURE VIII.

*Concerning several other Phænomena or Appearances, which depend on the Motion of the Earth,*



SINCE the *Earth* turns so round the *Sun*, that its *Axis* always remains parallel to itself, it seems necessary that this *Axis*, at different Seasons of the Year, should point to different *fixed Stars*, and that the *Star* or Point of the Heavens, which is directly over the Pole of the *Earth* in the Summer, should not be so directly over it in the Winter; but that the *Axis* should point to another *Star*, whose Distance from the former should be equal to the whole Diameter of the *Earth's* Orbit.

*The Axis of the Earth ought to point to different Stars at different Times of the Year.*

FOR let  $ACBD$  be the Orbit of the *Earth*, in whose Center is the *Sun*  $S$ ;  $AB$  the Diameter of the Orbit: When the *Earth* is at  $A$ , its *Axis* is directed to a *Star*  $E$ , which is directly over the Pole of the *Earth*: Now when the *Earth* comes to the opposite Point of the Orbit  $B$ , the *Axis* being in a Position parallel to its former Position, it will no longer point to the *Star*  $E$ , but to another *Star*  $F$ , which two *Stars* will be distant from each other, the whole Length of the Diameter of the great Orbit. But the angular or observable Distance of the Stars is the Angle  $EBF$ , which is equal to the Angle  $AEB$ , by the 29th Prop. 1st Book of *Euclid*. But the Angle  $AEB$  is the Angle under which the Diameter of the great Orbit, or Orbit of the *Earth*, is seen from the *Star*  $E$ , which Angle

Plate IV.  
Fig. 1.



Lecture VIII. Angle  $EBF$  or  $AEB$  is called the *Parallax of the great Orbit*; and if it could be observed, we might by it find the Distance of the *Star E*, from the *Earth*, in respect of the *Sun's* Distance from us. For in the Triangle  $EAB$ , we have the Angle  $E$ , which is equal to the Angle  $EBF$ , which we suppose we can observe; we have likewise the Angle  $EAB$ , which in the *Equinoctial Points* is always a right Angle; and in the *Solstices* it is equal to the Inclination of the *Earth's Axis* to the Plane of the *Ecliptick*, and is always equal to the visible Distance of the *Sun* from the *Pole*: Hence in this Triangle, we have all the Angles; we have likewise the Side  $AB$ , and consequently, by *Trigonometry*, we can find the Side  $AE$ , or  $EB$ , the Distance of the *Star E* from the *Earth*.

*This Parallax scarcely to be observed.* BUT the Truth is, that the Distance of the *Stars* is so great in respect of  $AB$ , and the Angle  $EBF$  is so very small, that there can be no Instruments made nice enough to observe it exactly; and they who have taken most Pains to find it out, could never observe it to be so great as one Minute; And since in the Observations of such small Angles, Errors are scarcely to be avoided, and such too as will in the Computation produce prodigious Differences in the Distances which depend upon them; we cannot safely trust such Observations: For if, with Mr. *Flamsteed*, we should suppose the Parallax, or the Angle  $EBF$ , to be 42 Seconds, and there be an Error committed in Observation, which makes the Angle 25 Seconds greater than it really is, (and no Man can be sure that he has not committed such an Error) the Distance of the *fixed Stars*, in that Case, will really be double of what our Observation makes it. But if the Observations happen to be less accurate, so that there may be a Minute or more between them and the Truth, (and most of our Observations are such) the Distance that arises from the Computations made upon such Observations, will be prodigiously wide of one another, and all of them very different from the Truth.

*The Distance of the Stars uncertain.*

HITHERTO



HITHERTO we have supposed the *Axis* of the *Earth* to have remained in an immutable Position, and to have continued in an exact Parallelism, and that the *Earth* had only two Motions, one Annual round the *Sun*, the other Diurnal round its *Axis*. But the *Astronomers*, from the Observations of many Years, have found that the *Axis* of the *Earth* has not exactly kept its Parallelism, but has deviated a little from that Position; so that tho' the Variation in the Space of two or three Years be scarcely sensible, yet in many Years, or in a Century or two, it is very observable: And therefore, while we were explaining the Appearances of one Year, we spoke nothing of this *Aberration*; for that could no ways disturb the *Phænomena* that were then to be explained; yet in the Compass of several Years, this Mutation or Change of the Position of the *Earth's Axis* becomes very remarkable. So the Direction of the *Axis* has been sensibly changed, tho' its Inclination to the Plane of the *Ecliptick* has remained the same; and from hence we find, that the *Axis* of the *Earth* has another Motion, which is here to be explained.

Let the Line DCH represent a Portion of the *Earth's Orbit*, and let the Center of the *Earth* be C; from which erect CE perpendicular to the Plane of the *Ecliptick*, meeting with the concave Surface of the Heavens in E: This Line CE will be the *Axis* of the *Ecliptick*, and E the Pole of it. Let CP be the *Axis* of the *Earth* produced to the Heavens; P will be the *Pole* round which the Heavens have an apparent diurnal Revolution. Through the two Points E and P, draw a great Circle EPA, which passing through the Poles of both the *Ecliptick* and *Æquator*, will be perpendicular to both those Circles. Let it meet with the *Ecliptick* in A; the Arch PA will measure the Angle PCH, which is the Inclination of the *Axis* of the *Earth* to the Plane of the *Ecliptick*; that is, it will be  $66\frac{1}{2}$  Degrees; and therefore the Arch EP, which is its Complement to a Quadrant,

Lecture VIII.

The Axis of the Earth does not preserve an exact Parallelism.

Plate IV.  
Fig. 2.

The Axis of the Ecliptick.



Lecture VIII. Quadrant, will be  $23\frac{1}{2}$  Degrees; which Arch will measure the Angle ECP, that the *Axis* of the

*The Pole of the World moves backward in a lesser Circle parallel to the Ecliptick.* Ecliptick and the *Æquator* make with one another. From the *Pole* E, describe thro' P a lesser Circle PFG, which will be parallel to the Ecliptick; and since the *Axis* of the *Earth* always keeps the same invariable Angle with the *Axis* of the Ecliptick, it will always be directed to some Point in the Periphery PFG, and the *Pole* of the World must always be somewhere placed in it: So likewise, if the *Axis* of the *Earth* retained the same Direction without any Change, as often as the *Earth* came to the Point of its Orbit C, the *Pole* of the Heavens would be constantly in the indivisible Point P: But we find, that the *Pole* of the World does constantly change its Place in the Periphery PFG; and the *Axis* of the *Earth*, which before pointed to P, after 72 Years will look to another Point Q, which is one Degree from P towards the *West*. And by this Means, the *Axis* of the *Earth*, or of the World, is carried in a *Conical Motion*, or describes the Surface of a *Cone*, whose Vertex is in the Center of the *Earth*, and its *Base* is the Circle PFG; and the *Pole* P will constantly move in the Periphery PFG, with a very slow and retrograde Motion, from the *East* to the *West*, and does not finish its Circulation in less than 25920 Years; after which Time the *Pole*, having left the *Star* at P, does again return thither. Hence it follows, that the *Star* which is now the *Polar*, and directly over the *Pole* of the *Earth*, after 12960 Years, which is half the Period of the *Polar* Revolution, will be 47 Degrees distant from the *Pole*, which will then be directed to G.

*The Solstitial Colure.* THE Circle EPA being perpendicular to both the Ecliptick and the *Æquator*, will be the *Solstitial Colure*, and A will be the *Solstitial Point*, which Point of the Ecliptick is most distant from the *Æquator*: Now, after the *Axis* of the *Earth* produced comes into the Position CQ, if there be drawn through the Poles of the Ecliptick



tick and the *Æquator* the Circle *E Q B*, this Circle will then be perpendicular to both *Æquator* and *Ecliptick*; and therefore, when the *Axis* of the *Earth* is in the Position *C Q*, the Circle *E Q B* will be the *Solstitial Colure*, and the *Solstitial Point* will be *B*, where that Circle intersects the *Ecliptick*; and therefore the *Solstitial Points* will move backwards equally with the *Poles*; the Motion of the *Pole* being in the Circle *P Q G*, which is parallel to the *Ecliptick*, the Arches *P Q* and *A B* will be like or similar; so that when *P Q* is an Arch of one Degree, *A B* will likewise be an Arch of one Degree.

The Solstitial Points move backward.

HENCE the *Solstitial Points* will always be receding from the *Stars* backwards, so that if the *Solstitial Point* be this Day near the *Star A*, after 72 Years it will be in *B*, one Degree removed towards the *West* of the *Star A*. And since the *Solstitial Points* move constantly backwards, the *Æquinoctial Points*, which are always 90 Degrees distant from the *Solstices*, will also move constantly backwards; and so likewise must all the other Points of the *Ecliptick* necessarily move back, equally with the *Solstices*, because they keep constantly the same Distances from them. Thus, since between the *Solstice*, and the Intersection of the *Æquator* and the *Ecliptick*, there are 90 Degrees, or a Quadrant of a Circle, when the *Solstice* has moved one Degree *Westward*, the *Æquinoctial Intersection* must likewise move one Degree *Westward*; otherwise they could not always keep the same Distance from one another. Therefore the *Æquinoctial Points*, and all the other Points of the *Ecliptick*, do move continually backwards, or towards the *West*. And this Motion is said to be in *Antecedentia*, to the *Westward*, and contrary to the Order of the Signs: As the other Motion, whereby the *Earth* and all the Planets are carried round the *Sun* to the *Eastwards*, is said to be in *Consequentia*, in sequence, or according to the Order of the Signs, that

The Æquinoctial Points move likewise backward.

The Motions in Antecedentia.

The Motions in Consequentia.



Lecture VIII. that is, from  $\Upsilon$ , to  $\delta$ ,  $\Pi$ , &c. And this backward Motion of the *Æquinoctial* Points is called the *Precession* of the *Æquinoxes*, by which they are carried constantly back unto the preceding Signs or *Stars*, and fall more and more behind the succeeding *Stars*.

*The Motion of the Æquinoctial Points backwards makes the Stars seem to move forwards, or to the East.* SINCE the *fixed Stars* remain immoveable, and the common Intersection of the Equator and the Ecliptick constantly falls backward, it must necessarily happen, that the Distance of the *Stars* from the *Æquinoctial* Points be constantly changed, and the Intersections moving *Westward*, the *Stars* will seem to remove more and more *Eastward* in respect of the *Æquinoctial* Points: And therefore the Longitudes of the *Stars* which are computed from the first Point of  $\Upsilon$ , or the vernal Intersection of the *Æquator* and Ecliptick, must constantly increase; and all the *Stars* will seem to have a Motion *Eastward*, not that they have really any such Motion, but because the *Æquinoctial* Point has a contrary Motion to the *West*; so that the Distances of the *Stars* or their Longitudes from the first Point of  $\Upsilon$  reckoned *Eastwards*, becomes constantly greater.

*The Constellations have changed their Places.* HENCE it is, that all the Constellations have changed their Places, and have deserted the Stations they kept, when they were observed by the first *Astronomers*. Thus the Constellation of the *Ram*, which in *Hipparchus's* Time was near the Vernal Intersection of the *Æquator* and Ecliptick, and gave its Name to that Portion of the Ecliptick, is now removed from that Intersection a whole Sign, or a twelfth Part towards the *East*, and is got into the Sign or Portion of the Ecliptick called  $\delta$ , or the *Bull*: Thus also the Constellation *Taurus*, or the *Bull*, does now reside in *Gemini*, or the *Twins*; and the *Stars* which are called *Twins*, are at this Day advanced to  $\zeta$ , or the *Crab*; the *Stars* in the *Crab* are got into the Place which was formerly possessed by the *Lion*, and the *Lion* has driven the *Virgin* a whole Sign forward; and so every Constel-



Constellation has since the first Observation changed Place with the following. But here it is to be observed, that tho' the Constellations or Images have left their Places, yet the twelve Portions of the Ecliptick, which are called *Dodecatimoria*, retain still the same Names which they had at first in the Time of *Hipparchus*: But to distinguish them from the Constellations, the Portions of the Ecliptick are called *Anastrous* Signs, or Signs without *Stars*; and the Constellations are called the *Starry* Signs.

Lecture  
VIII.

SOME antient *Astronomers* supposed the Intersections of the *Æquator* and Ecliptick to be immoveable; and because they found that the *Stars* changed their Distances from these Intersections, they therefore imagined the Orb or Sphere in which the *fixed Stars* were placed, to have a slow Revolution about the *Poles* of the Ecliptick; so that all the *Stars* performed their Circulations in the Ecliptick, or its Parallels, in the Space of 25920 Years; after which Time the *Stars* would again return to their former Places. This Period of Time, which is five times greater than the Age of the World, they called the great Year; and imagined that when it was finished, every Thing would begin again, and all Things happen and come up in the same Order they do now.

The great  
Year.

THE physical and efficient Cause of the Precession of the Equinoxes, was unknown to all the *Astronomers* before *Sir ISAAC NEWTON*; none of them being able to guess from whence it did proceed. But *Sir ISAAC NEWTON*, having considered the Laws of Motion and Gravity, hath clearly demonstrated, that it doth arise from the broad spheriodical Figure of the *Earth*: And that this broad spheriodical Figure arises from the Rotation of the *Earth* round its *Axis*.

ALTHO' the *Earth* in its annual Motion does so go round the *Sun*, that it always performs its Period in equal Intervals of Time; yet its Motion in its Orbit is observed not to be equable

The Motion  
of the Earth  
in its Orbit  
not equable,



Lecture  
VIII.

Our Summer is eight Days longer than Winter.

The apparent Diameter of the Sun greater in Winter than Summer.

ble and uniform, but in some Places it moves quicker, in other Places it slackens its Pace; and therefore the apparent Motion of the *Sun* in the Ecliptick cannot be regular and uniform: And he is not observed to go thro' the same Space of the Ecliptick every Day. In our Summer he is observed to go with a slower Motion, in our Winter he moves somewhat faster; and the Difference of these Motions in Summer and Winter is such, that his Place in the Ecliptick is sometimes two Degrees above what it would be, if he had constantly kept the same Pace; and sometimes it is two Degrees less: On which account the *Sun* is observed to spend near eight Days more Time in the *Northern* Signs of the Ecliptick, than in the *Southern* Signs; so that from the Time of the *Sun's* being in the *Vernal* *Æquinoctie*, till his coming into the *Autumnal*, there are  $186\frac{1}{2}$  Days; in which Time by his apparent Motion he is seen to describe one half of the Ecliptick. But from the *Autumnal* *Æquinoctie* to the *Vernal*, there are only  $178\frac{1}{2}$  Days, in which Space of Time he finishes his Course thro' the other half of the Ecliptick, and visits all the *Southern* Constellations. We are also assured by the Observations of *Astronomers*, that the apparent Diameter of the *Sun* in Winter, when the Motion of the *Sun* is quickest, is greater than the apparent Diameter in the Summer, when he slackens his Pace; and the Difference is so great, that when the *Sun* appears biggest, he is seen under an Angle of 32 Minutes 47 Seconds; but when he appears least, he subtends an Angle only of 31 Minutes and 40 Seconds; and therefore the *Sun* must be farther from us in Summer than in Winter.

SOME *Astronomers*, too pertinaciously keeping to circular Orbits, that they might give a satisfactory Account of these Appearances, supposed that the *Earth* did really move with an equable Motion in the Periphery of a Circle, and that if it were seen from the Center of that Circle,

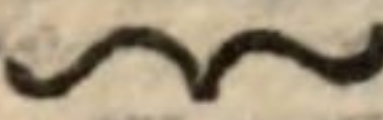


Circle, it would be observed to describe equal Angles round it; but they supposed the *Sun* to be removed from that Center at some Distance. Lecture VIII.

Let the Circle *ABCD* be the Orbit of the *Earth*, whose Center is *E*, and imagine the Center of the *Sun* not to be in *E*, but in *S*. Plate IV.  
Fig. 3.  
The Motion  
of the Earth  
in an Eccen-  
trick Circle. Now when the *Earth* is in *A*, the *Sun* will be observed in the Point  $\gamma$ ; and when the *Earth* comes to *B*, the *Sun* will be observed in  $\delta$ : And again, the *Earth* being arrived at *C*, the *Sun* will appear in  $\epsilon$ ; so that while the *Earth* describes the Arch *ABC*, which is more than a Semicircle, the *Sun* will appear to have gone thro' but one half of the Ecliptick; and the *Sun* will seem to have performed his Journey thro' the other half, while the *Earth* is describing the other Portion of her Orbit *ADC*. Now since the Arch *ABC* is greater than the Arch *ADC*, it is easy to see, that the *Sun* must take more Time to describe, by its apparent Motion, that half of the Ecliptick  $\gamma, \delta, \epsilon$ , than the other  $\epsilon, \psi, \gamma$ . Moreover, when the *Earth* is in *B*, it is further distant from the *Sun*, than when it is in *D*: And if its Motion were in itself perfectly equable, yet when it is seen from the *Sun*, which is not the Center of equable Motion, it would from thence appear to be unequal: In *B* it would appear to be slowest of all; and in *D* to be the quickest of all. But the apparent Motion of the *Sun* in the Ecliptick is constantly equal to the Motion of the *Earth* seen from the *Sun*; and therefore by this Supposition we can give an easy Account why in our Summer the *Sun* appears to have a slow Motion, and in the Winter a quicker; so that the unequal Motion of the *Sun* or *Earth* is not so in reality, but only Optical and Apparent; arising only from this, that the *Sun* is not exactly in the Center of the *Earth*'s Orbit in *E*, but at some Distance from it at *S*: So they affirmed, that a Spectator in *E* would always



Lecture always observe, that the *Earth* had a most exact uniform Motion round that Center in its Orbit.

VIII.  THIS *Hypothesis* appears at first Sight to be simple enough, and to answer well the Appearances we have related; and all the *Astronomers* before *Kepler*, embraced it as a true *Hypothesis*. For they held it for an undoubted Truth, that all the Motions of the Heavens were exactly circular, and in themselves equable: But after the great *Kepler* had more accurately surveyed these Motions; and relying upon the Observations of the most industrious *Tycho Brahe*, he then found, that the circular *Hypothesis* would by no means answer to the true Motions of the *Planets*: And by a most certain and infallible Method of Reasoning, he has shewn, that the Motions of the *Planets* are neither equable in themselves, nor are their Orbits exact Circles. For by the Observations of *Tycho*, he has proved beyond all Dispute, that the Figure of a planetary Orbit is an *Ellipse*, which is deficient from a Circle, or of the Form of an Oval; and that the *Planets* Motion in this *Ellipse* is really unequal, sometimes quicker, and sometimes slower; and that, according to its Distance from the *Sun*, the *Planet* slackens or quickens its Motion.

The true Motions of the Planets are neither in Circles nor equable.

The Elliptick Orbits of the Planets.

Plate IV.  
Fig. 4.  
The Description of an Ellipse.

Now the *Ellipsis* is a curved Line Figure, which the *Geometers* commonly shew by cutting a Cone or a Cylinder obliquely: But its Nature will be more clearly apprehended by Beginners, from the following Description: Imagine two small round Sticks to be fastened in any Plane or Paper, one in the Point H, the other in the Point G; and suppose a Thread doubled with the two Ends tied together, whose Length must be greater than the Distance of the Points G and H, which Thread put over the two round Sticks: And let there be a Pen put in the doubling of the Thread, which may keep it always stretched with the same Force. This Pen, going in this Manner round, will describe by its



its Motion a curve Line, which is the *Ellipse* we now speak of. And if without changing the Length of the Thread, we should bring the round Sticks a little closer together, we shall then have another *Ellipse* of a different Kind from the former, and which will come nearer to a Circle: And by bringing them still nearer, we shall always change the Form of our *Ellipse*, and bring it nearer to a Circle, till the Sticks come to be joined together in one; and then the Pen in the doubling of the Thread will describe an exact Circle. Either of the Points G or H is called the *Focus* or Nave of the *Ellipsis*; and if we bisect HG in C, the Point C is called its Center; the Line DK passing thro' each *Focus*, and at each End meeting with the *Ellipse*, is called its *Axis*: Hence it is evident, that if from any Point of the *Ellipsis*, there be drawn to the two *Focus*'s, as for Example from B, two Lines BH and BG, these two Lines joined together will always be equal to the *Axis* of the *Ellipsis*, and likewise equal to the Length of the Thread, bating the Distance of the two *Focus*'s.

Now tho' this be the Form of the Orbit which the *Planets* describe; yet the Place of the *Sun* is not the Center of it, but he takes his Residence in one of the *Focus*'s: And the *Axis* of the *Ellipse* AP is called the Line of the *Apsides*; the Point A is termed the *higher Apsis*, and the *Aphelion*; the Point P is called the *lower Apsis*, and the *Perihelion*: And SC the Distance between the *Sun* in the *Focus* and the Center, is called the *Excentricity*. If from the Center C, there be erected upon the *Axis* the Perpendicular CE, meeting with the Orbit in E, and there be drawn from the *Focus* the Line SE; this Line is called the *Mean Distance* of the *Planet* from the *Sun*, which is equal to half the *Axis*; it exceeding the shortest Distance by as much as the longest Distance exceeds it.

The Focus  
or Umbili-  
cus.

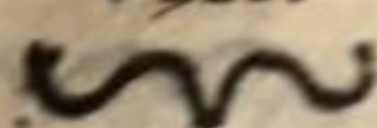
The Axis.

Plate IV.

Fig. 5.

The higher  
Apsis or  
Aphelion.The lower  
Apsis or  
Perihelion.  
The Excen-  
tricity.The Mean  
Distance.



Lecture  
VIII.

IN the planetary Orbits, the Forms of the Ellipses do not differ much from Circles; and in the Orbit of the *Earth*, the Excentricity  $SC$  is only 17 of such Parts as  $SE$  the mean Distance consists of 1000, which Excentricity is but half of that which the *Astronomers* that supposed circular Orbits, attributed to the Distance of the *Sun* from the Center.

The Rule  
by which  
the Planets  
Motions are  
regulated,  
is the equa-  
ble Descrip-  
tion of El-  
liptick  
Areas.

THE Motion of a *Planet* in the Periphery of an Ellipse, is not at all equable; yet it is regulated by a certain immutable Law, from which it never deviates; which is, that a Line or Ray drawn from the Center of the *Sun* to the Center of the *Planet*, which is carried about with an angular Motion, does so move, that it describes or sweeps an Elliptick Area, always proportional to the Time. Thus let the *Planet* be in  $A$ , from whence in a certain Time let it go to  $B$ ; the Space or Area the Ray  $SA$  describes, is the Triline  $ASB$ : When afterwards the *Planet* comes to  $P$ , and from the Center of the *Sun*  $S$ , there be drawn the Line  $SD$ , so that the Elliptick Space or Area  $PSD$ , may be equal to the Area  $ASB$ ; then in that Case, the *Planet* will move thro' the Arch  $PD$ , in the same Compass of Time that it did thro' the Arch  $AB$ , which Arches must be unequal, and nearly in a reciprocal Proportion to their Distances from the *Sun*; for because of the equal Area's, the Arch  $PD$  must be so much in Proportion greater than the Arch  $AB$ , as  $SA$  is greater than  $SP$ . This Law is sufficiently demonstrated by the most sagacious *Kepler*, in his Book which he intituled, *Commentaries on the Motion of the Planet Mars*. And unto this his Invention, all the *Astronomers* do now give their Assent; for there is no other Rule to be found, which so well satisfies all the Appearances of the *Planets* Motions.

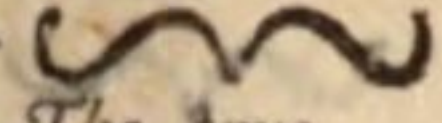
The Mean  
Anomaly.

AN Arch of a Circle, or an Angle, or the Elliptick Area  $ASG$ , taken proportional to the Time in which the *Planet* descends from  $A$  to  $G$ , is called the *Mean Anomaly* of the *Planet*. But the



the Angle  $ASG$ , when the *Planet* comes from  $A$  to  $G$ , is called its *true Anomaly*. But when the Motion of the *Planet* is reckoned from the vernal Intersection of the *Æquator* and the *Ecliptick*, or from the Beginning of  $\Upsilon$ , it is called its *Motion in Longitude*; which is either a mean Motion, such as the *Planet* would have, did it move uniformly in a Circle round the *Sun*, or else the true Motion where-with the *Planet* describes its Orbit, and is reckoned by the Arch of the *Ecliptick* it is seen to describe; which true Motion is sometimes accelerated, and sometimes retarded, according to the Distance of the *Planet* from the *Sun*, in the various Points of its Orbit.

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VIII.

  
The true  
Anomaly.  
The Motion  
in Longi-  
tude.

By this Means, for any given Time after that the *Planet* has left its *Aphelion*, we find out its Place in its Orbit; viz. Let the Area of the Ellipse be so divided by the Line  $SG$ , that the whole Ellip-  
rick Area may have the same Proportion to the Area  $ASG$ , as the whole periodical Time wherein the *Planet* describes its Orbit, is to the Time given; and then  $G$  will be the Place of the *Planet* in its Orbit. The *Geometers* have given several Methods for dividing in this Manner the Area of an Ellipse; some of which we will shew in its proper Place.

The Deter-  
mination of  
a Planet's  
Place in its  
Orbit.

SINCE in our Summer we are further from the *Sun*, and when Winter comes on, we begin to approach him; some may wonder why the *Earth* grows warmer, while it is still further removing from the *Sun*; and again in the Winter, why it should be colder notwithstanding its nearer Access to him. But we must observe, that the Degrees of Heat and Cold do not altogether depend upon the Distances from the *Sun*; but there are other powerful and concurring Causes, which have certain Effects in this Matter: For, first of all, the direct Force of the *Sun's* Rays is much stronger, than when they are received obliquely: Now in the Winter the Rays fall upon the *Earth* very obliquely, and their Power is not only diminished on the Account of their Obliqueness, but

Why the  
Sun's Heat  
is greater, as  
he is further  
from us.



Lecture also because the Light is not so dense, there being  
 VIII. much fewer Rays which can come to a certain Portion of the Surface to heat it. Moreover the *Sun* being low in the *Horizon* all the Winter, the Beams pass thro' a much greater Quantity of Air, or are deeper immersed in our Atmosphere in the Winter, than they are in Summer, when the *Sun* approaches nearer to our Vertex, and the Force of the Rays is broke by the Reflections on so many Particles of Air: And the Difference is so very great, that when the *Sun* is in the *Horizon*, we can look upon him without hurting our Eyes; but when he rises higher, there is no enduring his Sight without blinding us.

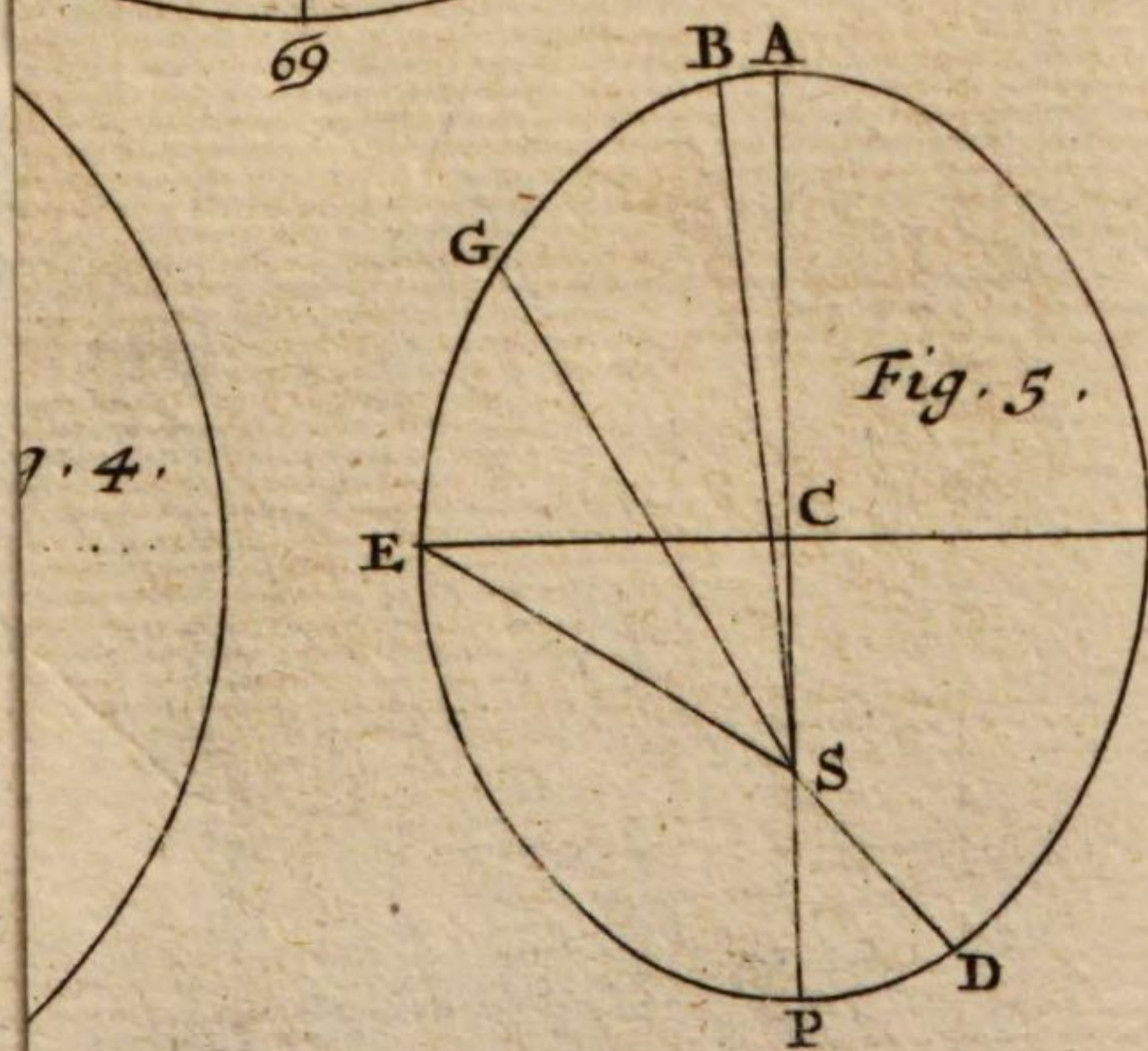
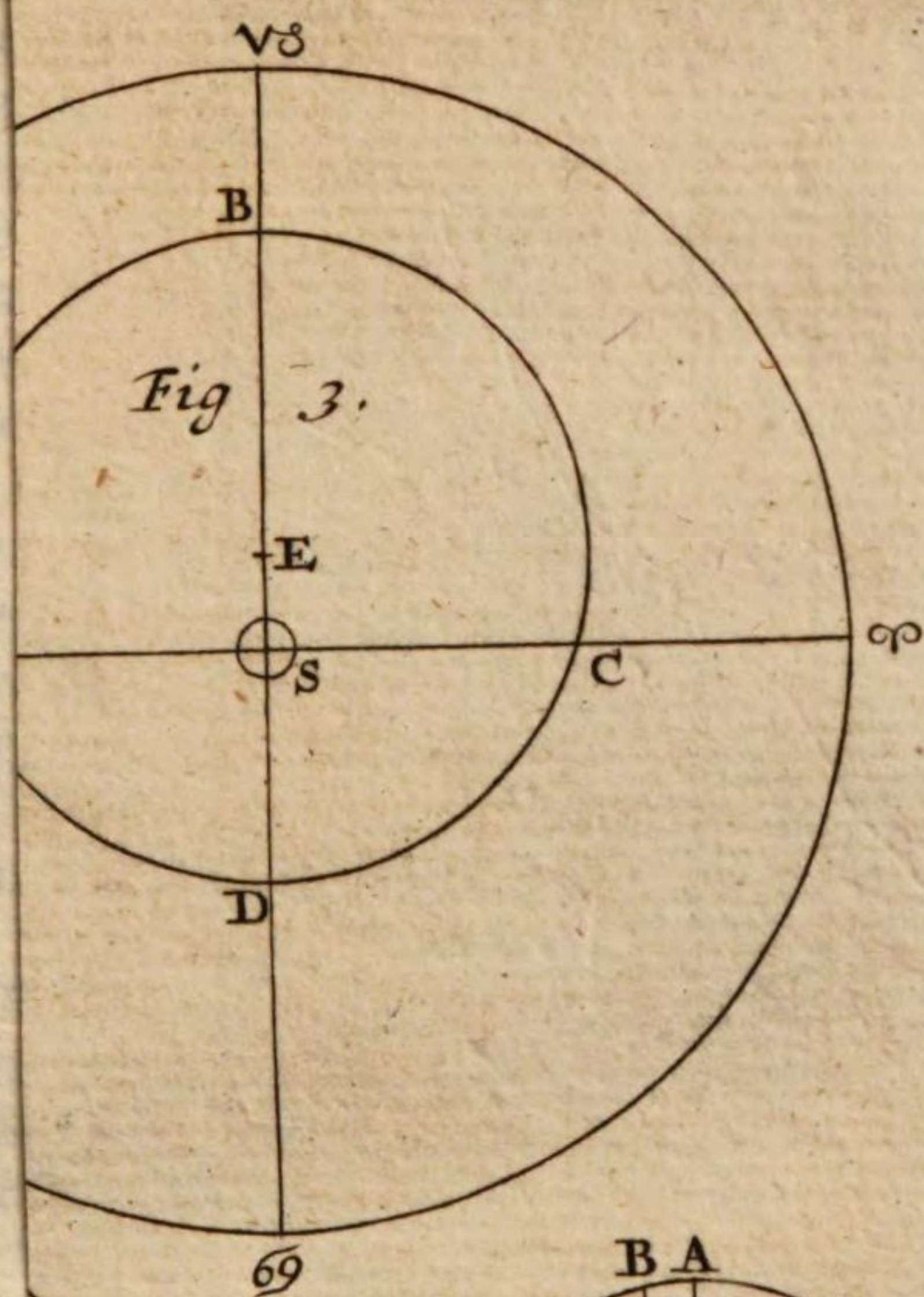
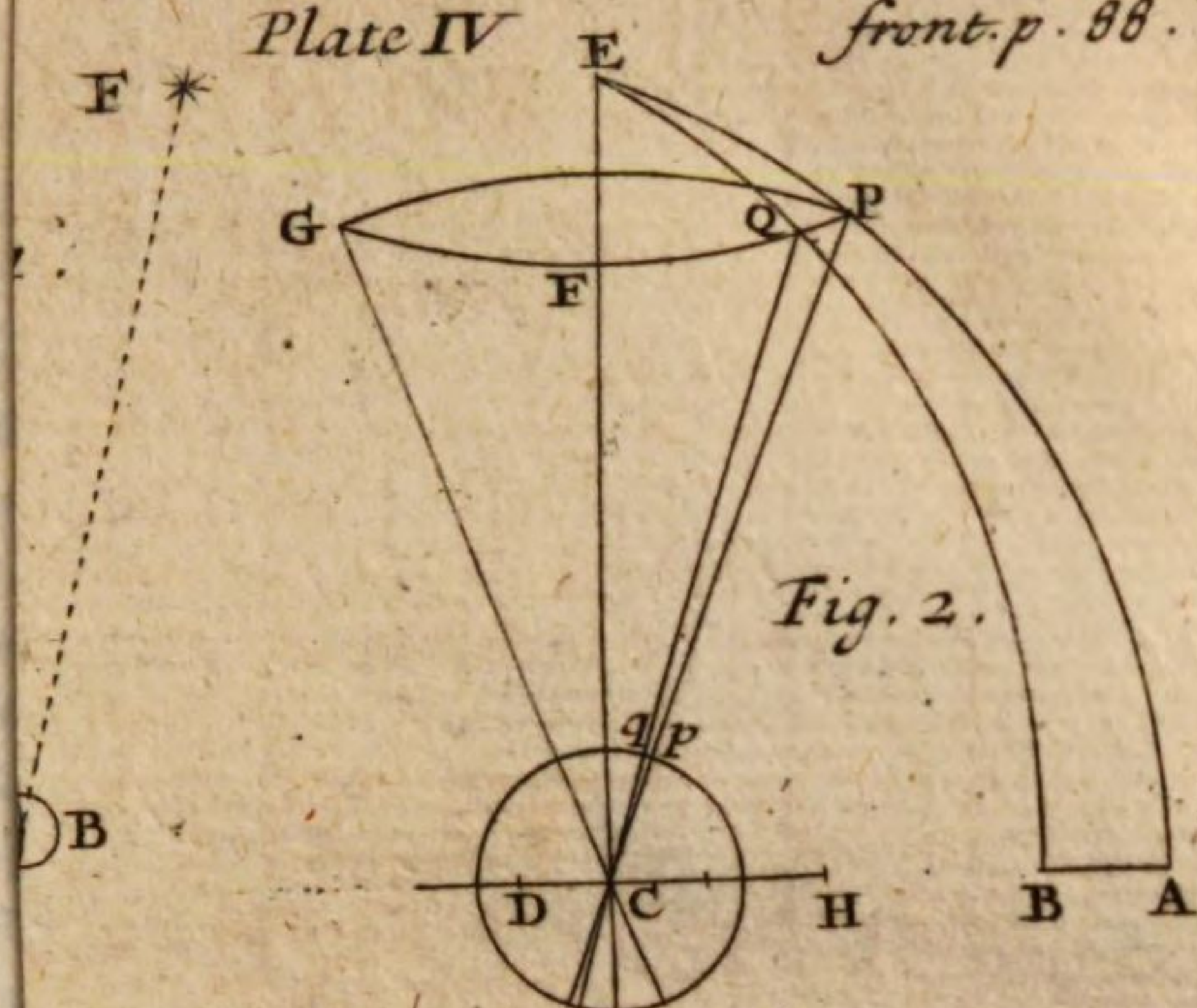
*The Days  
 longer than  
 the Nights,  
 increase the  
 Heat.*

BUT there is another very powerful Cause which produces the Variety of Seasons; which is, that the longer any hard and solid Body is exposed to the Fire, the hotter it grows. Now in the Summer for sixteen Hours we are continually in the *Sun's* Heat, and we have only eight Hours in the Night to cool: The contrary of which happens in the Winter, and therefore it can be no Wonder, that there should be so great a Difference of Heat and Cold, in these two Seasons.

SINCE the Power of the *Sun* is greatest when his Rays fall upon us most directly, and when the Days are longest; it would seem that the greatest Heat ought to be when the *Sun* enters the Tropick of  $\odot$ ; for then the *Sun* comes nearest to our Vertex, and lieth longest upon us. But Experience shews us, that we have the greatest Heat after that the *Sun* has left the Tropick; and the Season becomes warmest about the End of *July*, in the *Dog-Days*, when the *Sun* has passed the Tropick, and is removed from it above a whole Sign.

THAT we may give the true Cause of this Effect, it is to be observed, that the Action of the *Sun*, by which all Bodies are heated, is not transient, as its Illumination is, but permanent: So that a Body which has been once heated by the *Sun*, retains its Heat for some Time after the *Sun* has gone







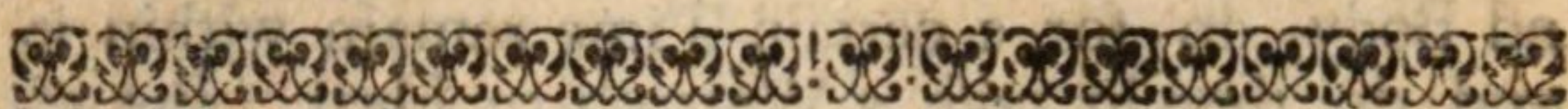




gone off it: So that the heating Particles which Lecture  
 flow from the *Sun*, and are absorbed by the heat- VIII.  
 ed Body, do for a certain Time remain within it, and do therein raise a Warmth or Heat. But afterwards, when these Particles fly off, or lose their Force, the Body begins to cool: And therefore, if the heating Particles, which are constantly received, be more than they which fly away, or lose their Force, the Heat of the Body must continually increase. And this is our present Case: After the *Sun* has entered the *Tropick*, the Number of Particles which heat our Atmosphere and *Earth*, does constantly increase, there entering more in the Day-time than what we lose in the Night-time, and therefore our Heat must grow greater. Let us suppose, for Example's sake, that there are a hundred heating Particles received in the Day-time in *Sun-shine*, and the Night being much shorter, there should fly off only fifty of them, other fifty still remaining there to excite Heat: The next Day, the *Sun* acting with almost the same Force, will impart another hundred Particles, of which no more than one half will fly away in the Night; so that on the Beginning of the third Day, the Number of Particles exciting Heat, will be increased by one Hundred: And thus, while there are more Particles that excite Heat received in the Day-time, than what fly away in the Night, the Heat will constantly grow stronger. But then, as the Days decrease, and the Action of the *Sun* becomes weaker, there will at last be more Particles that fly away in the Night-time, than what we receive in the Day-time; by which means the Heat of a Body will grow every Day less, and the *Earth* and Air will by Degrees cool.

*Why the Heat is not greatest, when the Sun is in the Summer Tropick.*





## LECTURE IX.

*Of the Moon, its Phases and Motion.*

*The Moon is  
an Atten-  
dant on the  
Earth.*



OF all the Bodies in the Heavens, if you except the *Sun*, the *Moon* appears to be the most splendid and shining Globe, and does more particularly belong to our *Earth*, of which she is an inseparable Companion. And she does constantly abide so much in our Neighbourhood, that if she were looked at from the *Sun*, she could never be seen to depart from us by an Arch greater than ten Minutes. She therefore is tied to the *Earth*, and waits upon her as an Attendant, going along with the *Earth* round the *Sun* in the Space of a Year; but in the mean Time she has a proper Orbit of her own, which she describes round the *Earth*, in the Time of a Month.

*It has va-  
rious Shapes  
and Phases.*

THE Primary Planets have the *Sun*, which they regard as a Center, for the Regulator of their Motions; and sometimes they approach us nearly, at other times they move away to a great Distance from us. But the *Moon*, like an Earthly Body, is kept in our Neighbourhood by a natural Propension or Gravity towards us; by the Means of which it is constantly turned out of a rectilinear Course, and is obliged to perform its Revolution round about us, in the Space of 27 Days and seven Hours. The *Moon* puts on several Phases and Appearances, and is always changing its Figure; and with the Multitude of her Forms, she has frequently puzzled the Minds and Understandings of those *Philosophers*, who have most contemplated



plated her: Sometimes she increases and grows bigger, then again she wanes, and diminishes, as it were, in old Age; sometimes she is bended into *Horns*, and then again she appears like a half Circle; at other times, she looks gibbous or hump-back'd, and immediately she assumes a full globular Face; and afterwards, by Degrees, she disappears, and loses all her Lustre; sometimes she enlightens us the whole Night, at other times she does not appear 'till late at Night: And even in a total Eclipse, she is frequently visible, though with a very languid and pale Countenance: Sometimes she keeps in the *Southern* Region of the Heavens; at other times, she rises high, and visits the *Northern* Hemisphere. All these Things were first found out by *Endymion* among the *Greeks*, who was the first among them who watched her Motions; and upon that Account, was supposed to have fallen in Love with her.

THE *Moon*, like the *Earth*, is a dark, opake, and spherical Body; and only shines with the borrowed Light of the *Sun*: For it is the *Sun* who is the great Luminary in our System, and who always illustrates that Half of the *Moon's* Body, which is turned towards him; whilst the other Half, which is opposite, is involved in Darkness: But the Face of the *Moon*, that can be seen by the Inhabitants of the *Earth*, is that which is turned toward the *Earth*: And therefore, according to the various Position of the *Moon*, in respect of the *Sun* and *Earth*, we do observe different Illuminations and Degrees of Illustration; at one time a larger, at another a lesser Portion of the illuminated Surface is to be seen; sometimes there is no Part of it visible, and sometimes we observe the Whole, and see the *Moon* with her full Face. But for the better Understanding of this Matter, we will explain it by a Figure. Let S represent the *Sun*, T the *Earth*, R T S a Portion of the *Earth's* Orbit, which it describes in its Annual Course round

*The Moon is  
a Spherical  
Opake Body.*

Plate V.  
Fig. 1, 2.



Lecture  
IX.

*The true  
Motion of  
the Moon  
from West  
to East.*

*The Circle in  
the Moon  
bounding  
Light and  
Darkness.*

*The Circle  
of Vision.*

*The Phases  
of the Moon  
explained.*

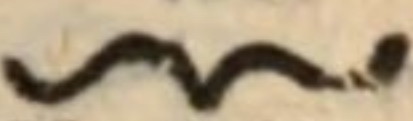
round the *Sun*. Let *ABCDEFGH* be the Orbit of the *Moon*, in which she turns round the *Earth* in the Space of a Month, from the *West* towards the *East*.

THIS Motion of the *Moon* is evident to our Senses; for if the *Moon* be observed to arrive at the Meridian any Night with a *fixed Star*, the next Night she will be 52 Minutes later in coming to the Meridian, or in *Southing*, than the *Star*; she having receded from the *Star* about 13 Degrees towards the *East*. Join the Centers of the *Sun* and *Moon*, with the right Line *SL*; and through the Center of the *Moon*, imagine a Plane *MLN* to pass, to which the Line *SL* is perpendicular: The Section of that Plane, with the Surface of the *Moon*, will produce the Circle which bounds Light and Darkness in her, and separates the enlightened Face, from the dark and obscure Side. In the same Manner, let the Centers of the *Earth* and *Moon* be joined by the right Line *TL*, which is perpendicular to a Plane *PLO*, passing thro' the Center of the *Moon*; that Plane will make, on the Surface of the *Moon*, the Circle which distinguisheth the visible Hemisphere, or that which is towards us, from the invisible, which is turned from us; which Circle may therefore be termed the *Circle of Vision*.

HENCE it is manifest, that whenever the *Moon* is in the Position *A*, in the Point of its Orbit opposite to the *Sun*, that then the Circle bounding Light and Darkness, and the Circle of Vision, do coincide; and that all the illuminated Face of the *Moon* will be turned towards the *Earth*, and be visible by its Inhabitants: And then the *Moon* is said to be full, and she shines all Night long; and in respect to the *Sun* she is said to be in *Opposition*: For the *Sun* and *Moon* are seen in opposite Parts of the Heavens, the one rising when the other sets. When the *Moon* comes to *B*, the whole illuminated Disk *MPN* is not turned towards the *Earth*, there being a Part of it *MP* not to be seen by

us;



us; and then the *Visible Illumination* will be deficient from a Circle, and the *Moon* will have a gibbous or humped Form, such as is marked in B.  The *Moon* arriving at C, where the Angle CTS is nearly right, there only one half of the illuminated Disk is turned towards the *Earth*, and to be seen from thence; and then we observe a *Half-Moon* as in C, and she is said then to be *Bisected* Half Moon, or the Moon Dichotomized. that is, cut in Halfs. In this Situation the *Sun* and *Moon* are a fourth Part of a Circle removed from each other; and the *Moon* is said to be in a *Quadrate Aspect*, or to be in her *Quadrate*. The Quadrate. The *Moon* going forward to D, the illuminated Face MPN has but a small Portion of itself turned towards the *Earth*, and the Side of the *Moon* turned towards the *Earth* is for the greatest part in Darkness: And therefore of the spherical Figure of the *Moon* which appears to us to be plain, that small Part which shines upon us, will seem to be bended into narrow Points or Angles, and will look like what we call Horns; for there the Circle bounding Light and Darkness with the Circle of Vision, doth form two small Angles at their Intersections, and the *Phasis* seen from the *Earth* will appear as in D. The *Moon* at last coming to E, will shew no Part of its illuminated Face to the *Earth*, but all the dark Side of the *Moon* will be turned towards it; and then the *Moon* disappears, and she is said to be in *Conjunction* New Moon, or the Conjunction. with the *Sun*, the *Sun* and she being in the same Point of the *Ecliptick*. This Position we call *New-Moon*. When the *Moon* advances further to F, she again assumes a horned or crooked Figure; and as before the *New Moon* the Horns were turned *Westward*, so now, after the Time of *New Moon*, they change their Positions and look *Eastward*. When the *Moon* has proceeded to G, and is again in a *Quadrate Aspect* with the *Sun*, she will appear bisected, and like a *Half-Moon*. In H she will be bigger, but will still be deficient from a whole Circle, and be seen gibbous: But



Lecture IX. But in A she will again appear circular, and in her full Splendor.

 THE Arch  $EL$ , or the Angle  $STL$ , contained under Lines drawn from the Centers of the *Sun* and *Moon* to the Center of the *Earth*, is called the *Elongation* of the *Moon* from the *Sun*. And the Arch  $MO$ , which is that Portion of the illuminated Circle  $MON$ , which is turned towards the *Earth*, and which is the Measure of the Angle that the Circle bounding Light and Darkneſs, and the Circle of Viſion, make with one another, is everywhere nearly ſimilar to the Arch of Elongation  $EL$ ; or, which is the ſame Thing, the Angle  $STL$  is nearly equal to the Angle  $MLO$ , which I thus demonſtrate: Produce  $SL$  at Pleaſure unto  $X$ , and the Angles  $TL P$  and  $MLS$  will be equal, they being both Right Angles: But the Angles  $OLS$  and  $PLX$  are alſo equal, becauſe they are vertical to each other; therefore taking away thoſe equal Angles, the Angle  $MLO$  will remain equal to the Angle  $TLX$ ; but the Angle  $TLX$  is the external Angle of the Triangle  $STL$ , and is therefore equal to both the inward and oppoſite Angles  $STL$  and  $TS L$ , by the 32d Propoſition of Book I. of *Euclid*. But the Angle  $TS L$  is exceeding ſmall, and next to nothing; for, when biggeſt in the Quadratures, it does ſcarce exceed ten Minutes of a Degree; the Diſtance of the *Moon* from the *Earth*, in compariſon of that of the *Sun*, being ſo ſmall, that the Angle which it ſubtends at the *Sun* vaniſhes. And therefore the Angle  $STL$  by itſelf, is nearly equal to the Angle  $MLO$ ; whence the Arch  $MO$  will be ſimilar or like to the Arch  $EL$ .

THE Semicircle  $OMP$ , ſince its Plane paſſes through the Eye, will be projected into a Right Line, or appear like a Right Line on the Disk of the *Moon*; but the Circle bounding Light and Darkneſs in the *Moon*, ſince it is ſeen obliquely from the *Earth*, will be projected into an Ellipſe, in which Form it will appear. Hence  
having



having the Elongation of the *Moon* from the *Sun*, Lecture IX.  
it will be an easy Matter to shew its *Phasis*, or

how it happens at that Time. Let the Circle  $COBP$  represent the Disk of the *Moon*, which *A Delineation of the Phasis of the Moon, for any Elongation. Plate V. Fig. 3, 4, 5.*  
is turned towards the *Earth*; and let  $OP$  be the Line in which the Semicircle  $OMP$  is projected, which suppose to be cut by the Diameter  $BC$ , at Right Angles; and making  $LP$  the Radius, take  $LF$  equal to the Cofine of the Elongation of the *Moon* from the *Sun*: And then upon  $BC$ , as the great *Axis*, and  $LF$  the lesser *Axis*, describe the Semi-Ellipse  $BFC$ . This Ellipse will cut off from the Disk of the *Moon*, the Portion  $BFCP$  of the illuminated Face, which is visible to us from the *Earth*.

By making  $LP$  the Radius,  $LF$  becomes the Cofine of the Elongation of the *Moon* from the *Sun*;  $PF$ , in that Case, must be the versed Sine of the said Elongation; and  $BFC$  (the Line which divides the illuminated and dark Parts of the Disk) will be an Ellipse, whose greater *Axis* is the Diameter of the Disk  $BC$ , and half the lesser *Axis* is the Semidiameter of the same Disk, diminished by the versed Sine of the Elongation. Suppose now that  $OBPC$  were the Disk of the *Moon* turned towards the *Earth*, and  $BFC$  the Semi-Ellipse dividing Light and Shadow: Draw any Line  $GHN$  parallel to the lesser *Axis*, and which meets with the greater *Axis* in  $M$ , by the Nature of the Circle and the Ellipse,  $LP$  will be to  $LF$ , as  $GM$  is to  $MH$ ; and by Division of the Ratio,  $LP$  is to  $PF$ , as  $GM$  is to  $HG$ ; and doubling of the Antecedents,  $PO$  will be to  $PF$ , as  $GN$  is to  $GH$ . The same Thing may be shewn of any other Line, which is parallel to the lesser *Axis*; and therefore by the 12th Prop. Book V. of *Euclid*, as  $PO$  is to  $PF$ , so will all the Lines  $GN$  be to all the Lines  $GH$ . But all the Lines  $GN$  compose or make up the whole *Lunar* Disk, it consisting of an infinite Number of Parallelograms, whose Heights are the Lines  $GN$ , and whose



Lecture IX. whose Bases are indefinitely little: So likewise all the Lines G H make up that Part of the Disk which is illuminated.

AND therefore, as P O is to P F, that is, as the Diameter of a Circle is to the versed Sine of the *Moon's* Elongation from the *Sun*; so is the whole Disk of the *Moon*, to that Part of it which is illuminated by the *Sun*. And hence the Illustration of the *Moon*, at any Time, is to its greatest Illustration, which is at *Full Moon*, as the versed Sine of the Elongation is to the Diameter of a Circle.

The Earth  
illuminates  
the Moon by  
a Reflex  
Light.

As the *Moon* by reflected Light from the *Sun* illuminates the *Earth*, so the *Earth* does more than repay her Kindness, in enlightening the Surface of the *Moon*, by the *Sun's* reflex Light, which she diffuses more abundantly upon the *Moon*, than the *Moon* does upon us: For the Surface of the *Earth* is above fifteen times greater than that of the *Moon*; and therefore, if both Bodies have the same Power of reflecting in proportion to their Bigness, the *Earth* would send back fifteen times more Light to the *Moon*, than it receives from it. For the *Earth* appears fifteen times bigger to the Inhabitants of the *Moon*, than the *Moon* does to us. In New Moons, the illustrated Side of the *Earth* is fully turned towards the *Moon*, and will therefore at that time illuminate the dark Side of the *Moon*; and then the *Lunarians* will have a *Full Earth*, as we in a similar Position have a *Full Moon*. And from thence arises that dim Light which is observed in the Old and New Moons, whereby, besides the bright and shining Horns, we can perceive the rest of her Body behind them, tho' but dark and obscure. Now, when the *Moon* comes to be in *Opposition* to the *Sun*, the *Earth* seen from the *Moon*, will appear in *Conjunction* with him, and its dark Side will be turned towards the *Moon*, in which Position the *Earth* will disappear; after the same Manner as the *Moon* does disappear to us in the Time of New Moon, or in her *Conjunction* with the



the *Sun*. After this the *Earth* will appear to the In-  
habitants of the *Moon* in a horned Form. In a  
Word, the *Earth* will shew all the same Appear-  
ances to the Inhabitants of the *Moon*, as the *Moon*  
does to us.

Lecture  
IX.

ALTHOUGH the *Moon* circulating round the *Earth* describes its Orbit in the Space of twenty-seven Days and seven Hours, which Space of Time is called a periodical Month; yet the Time the *Moon* takes to go from one Conjunction to the next, which is a synodical Month or a *Lunation*, is greater than the periodical. For while the *Moon* in its proper Orbit finishes its Course, the *Earth*, with this her Companion and its Orbit, are going on their Way round the *Sun*, and are advanced almost a whole Sign towards the *East*; so that the Point of the Orbit, which in the former Position was placed in a right Line joining the Centers of the *Earth* and *Sun*, is now more *Westerly* than the *Sun*: And therefore, when the *Moon* has again arrived to that Point, it will not yet be seen in Conjunction with the *Sun*.

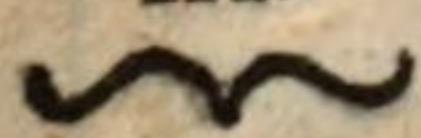
The periodical Month,  
and the synodical.

FOR let AB represent a Portion of the Orbit of the *Earth*, and when the *Earth* is in T, suppose the *Moon* in L, in Conjunction with the *Sun* in S: While the *Moon* leaves the Point L, and proceeds in describing its Orbit L A C D; the *Earth* in the mean time, by its Motion round the *Sun*, is carried thro' the Arch T t; and when it is come to t, the Orbit of the *Moon* is in the Position l a c d, and the Point of the Orbit L will now be in the Line t l, which is parallel to the former Line T L. Hence it is plain, that when the *Moon* has come to l, and described its whole Orbit, it is not then arrived at a Conjunction with the *Sun*; but it must still go further, and move thro' the Arch l M, before it can get between the *Earth* and *Sun*: And since the *Moon* finishes her Course in the Space of twenty-seven Days, in that Time the *Earth* will have completed an Arch of twenty-seven Degrees in the Ecliptick; now the Arch l M and T t are  
H alike

Plate V.  
Fig. 6.



Lecture IX. alike or similar, because the Lines  $LT$  and  $lt$ , being parallel, the Angles  $ltM$  and  $LSM$  are equal.

 But indeed it is required, that the *Moon* should describe a greater Arch than  $lM$ , before it gets between us and the *Sun*, because the *Earth* is still moving on in the mean time : And therefore the whole *Lunation*, or Time from *new Moon* to *new Moon*, is not finished but in the Space of twenty-nine Days and a half ; and the *Moon* does every Day recede from the *Sun*, about twelve Degrees and some odd Minutes ; which is called the diurnal Motion of the *Moon* from the *Sun*.

*The diurnal Motion of the Moon from the Sun.*

IF the Plane of the *Moon's* Orbit coincided with the Plane of the *Ecliptick*, that is, if the *Earth* and *Moon* moved both in the same Plane, the Way of the *Moon* in the Heavens seen from the *Earth*, would be exactly the same with the Circle the *Sun* is seen to describe ; only the *Sun* would be observed to describe that Circle in the Space of a Year, which the *Moon* does in a Month. Now in reality the Plane in which lies the *Moon's* Orbit, is not coincident with the Plane of the *Ecliptick* ; but these two Planes cut one another in a right Line, which passes through the Center of the *Earth* ; and they are inclined to one another in an Angle of about five Degrees.

Plate V.  
Fig. 7.

*The Moon does not move in the Ecliptick.*

LET  $AB$  be a Portion of the *Earth's* Orbit,  $T$  the *Earth*, and let the Circle  $CEDF$  represent the Orbit of the *Moon*, in which is the Center of the *Earth* ; with the same Center  $T$ , in the Plane of the *Ecliptick*, let there be described another Circle  $CGDH$ , whose Semidiameter may be equal to the Semidiameter of the *Moon's* Orbit ; these two Circles being in different Planes, and having the same Center  $T$ , will intersect each other in a Line  $DC$ , which passes through the Center of the *Earth* ; and  $CED$ , one half of the Orbit of the *Moon*, will rise above the Plane of the Circle  $CGH$ , towards the *North*. The other half of the Orbit  $DFC$  will be depressed below it, towards the *South*. The right Line  $DC$ , wherein the two Circles cut one another,



another, is called the Line of the *Nodes*; and the Lecture Points of the Angles C and D are called the *Nodes*. IX.

And the Node C, where the *Moon* ascends Northward above the Plane of the Ecliptick, is called the *ascending Node*, and the *Head of the Dragon*, and is thus marked ☊. The other D, from whence the *Moon* descends to the South, is named the *descending Node*, and the *Tail of the Dragon*, which by the *Astronomers* is marked in this Manner ☋. If the Line of the *Nodes* were immoveable; that is, if it had no other Motion, than that whereby it is carried round the *Sun*, it would always look to the same Point of the Ecliptick; that is, it would always keep parallel to itself, as we shewed the *Axis* of the *Earth* ought to do: But we find by Observation, that this Line of the *Nodes* does constantly change its Place, and shifts its Situation from *East* to *West*, contrary to the Order of the Signs; and by a retrograde Motion finishes its Circulation in the Compass of almost nineteen Years: After which time either of the *Nodes*, having receded from any Point of the Ecliptick, returns to the same again. And when the *Moon* is in the *Node*, she is also seen in the Ecliptick.

HENCE it is evident, that the *Moon* can never be observed precisely in the Ecliptick, but twice in every Period, that is, when she enters the *Nodes*; when she is in any other Place of her Orbit, she deviates from it, and is sometimes nearer, sometimes further removed from the Ecliptick, according as she happens to be nearer, or further off from the *Nodes*: But she is at her greatest Distance from the *Nodes*, when she is in the Points of her Orbit E or F, which are the middle Points between the *Nodes*; and these Points are called the *Limits*. The Distance of the *Moon* from the Ecliptick is called her *Latitude*, which is measured by an Arch of a Circle drawn thro' the *Moon*, perpendicular to the Ecliptick; the Arch of this Circle, intercepted between the *Moon* and the Ecliptick, measures the *Moon's Latitude*, or her Distance from the Ecliptick: And therefore such Circles, perpendicular to the Ecliptick, are called Circles

The Line of  
Nodes.

The ascend-  
ing Node, or  
the Dragon's  
Head.

The descend-  
ing Node, or  
the Dragon's  
Tail.

The retro-  
grade Motion  
of the Nodes.

The Limits.  
The Moon's  
Latitude.



Lecture of *Latitude*; the *Latitude* of the *Moon*, when it is  
 X. at the biggest, as in E or F, does never exceed five  
 Degrees, and about eighteen Minutes; which *Latitude*  
 is the Measure of the Angles at the *Nodes*.



## LECTURE X.

*Of the Inequalities in the Lunar Mo-  
 tions. The Face of the Moon, her  
 Mountains and Vallies.*

The Orbit of  
 the Moon  
 an Ellipse.

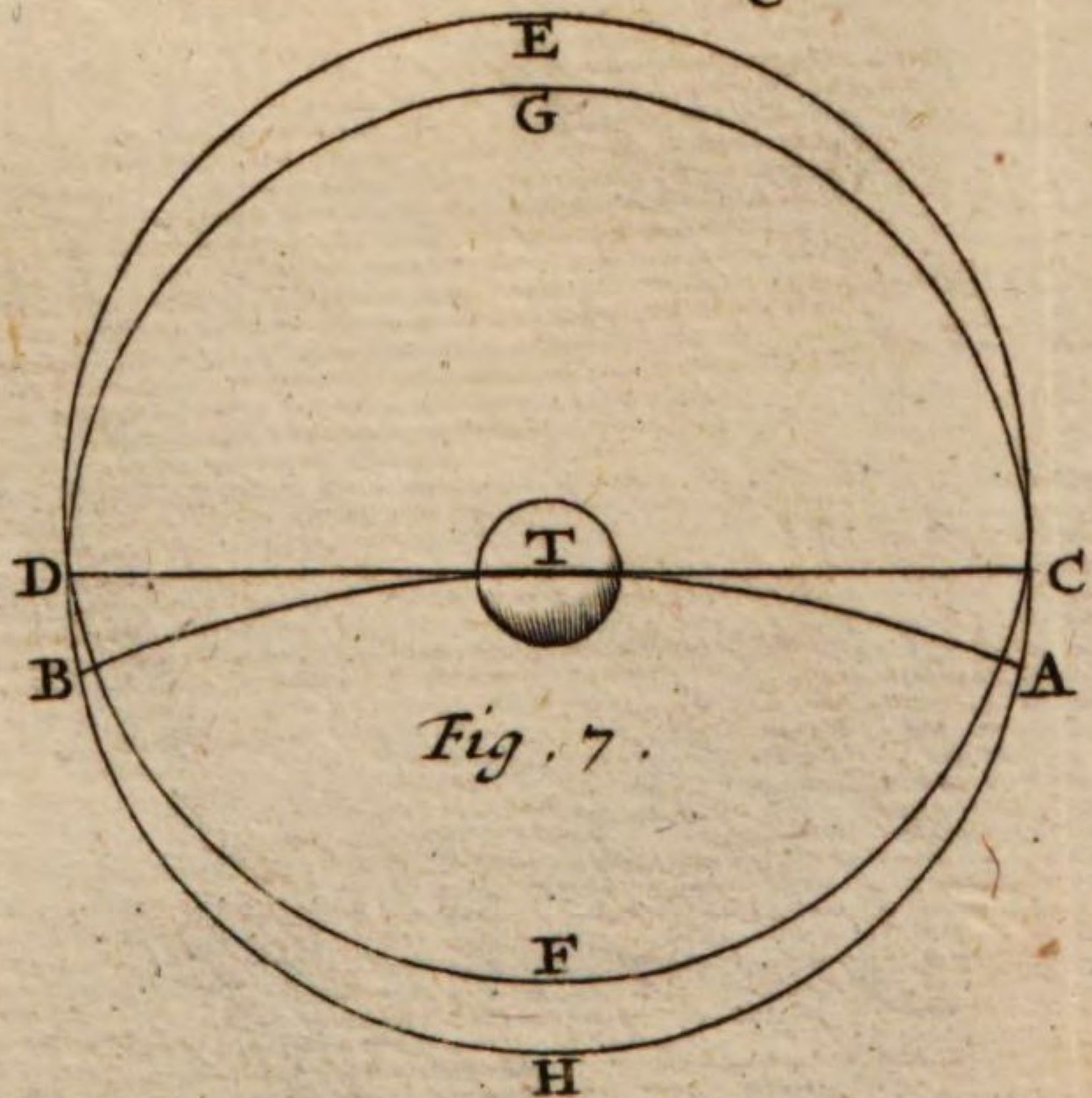
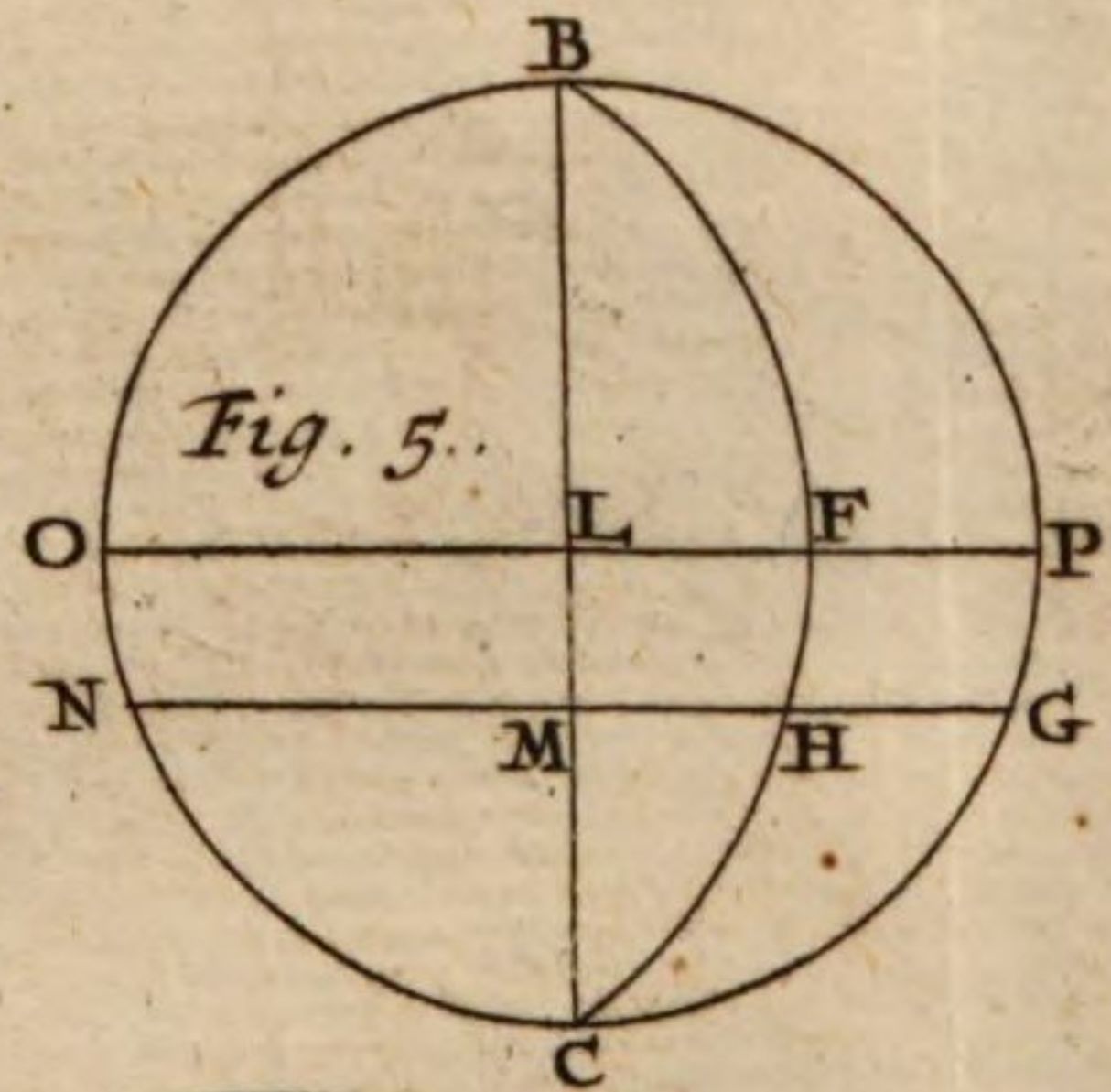
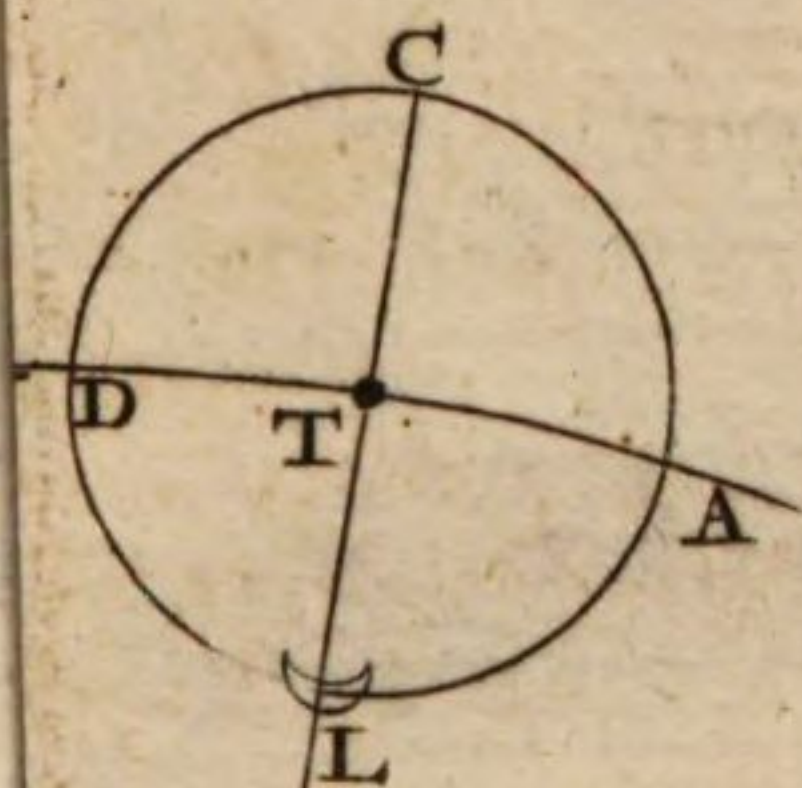
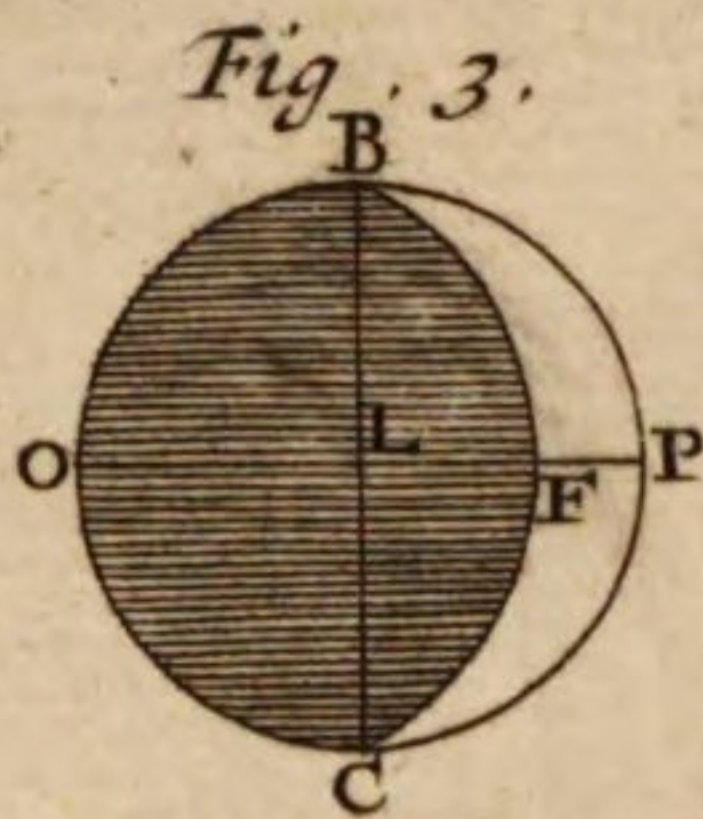
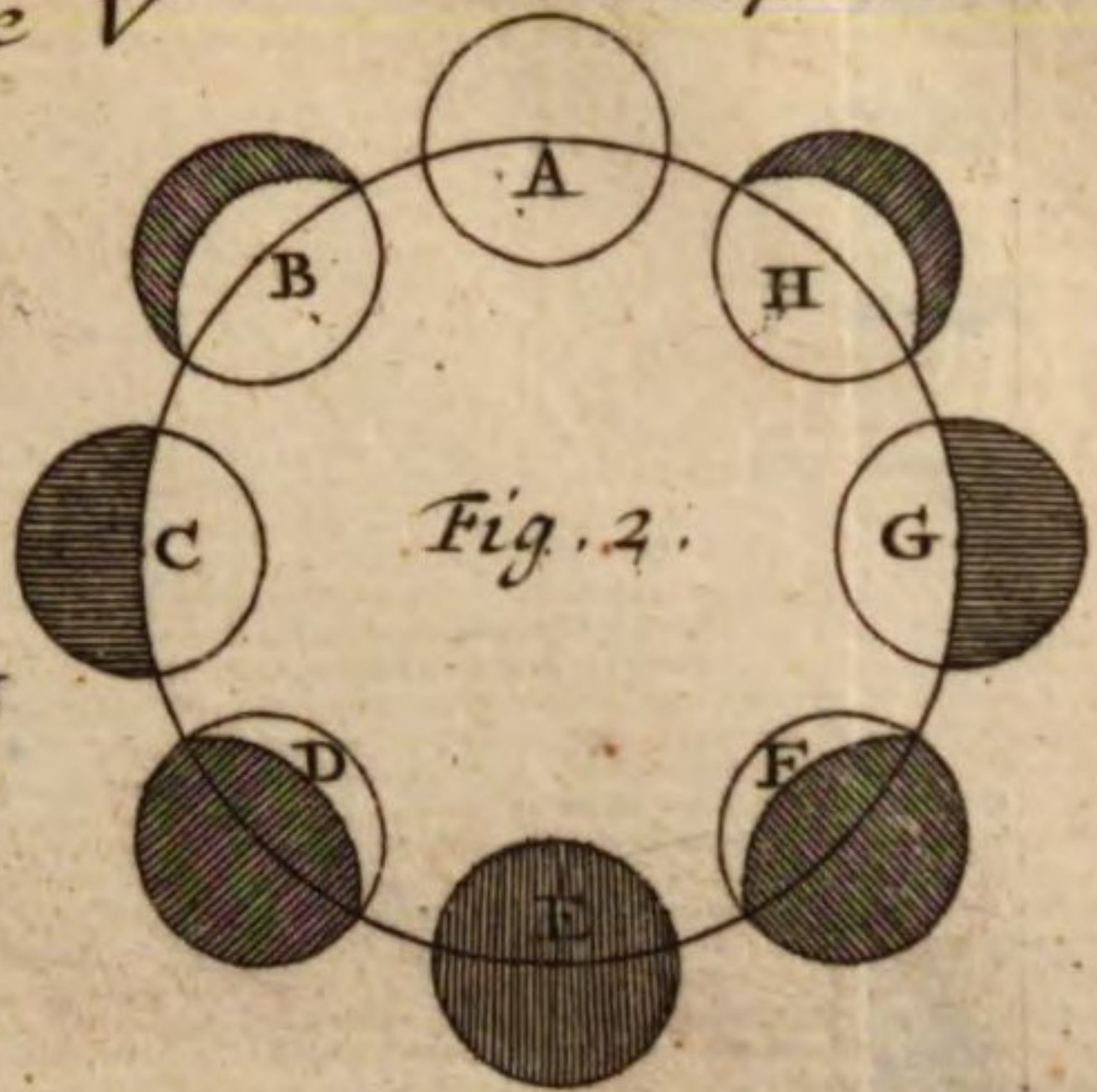


Plate VI.  
 Fig. 1.

The Moon's  
 Apogeeon,  
 and Peri-  
 geon.

OBSERVATIONS have discovered to us  
 that the Distance of the *Moon* from  
 the *Earth* does constantly change;  
 sometimes the *Moon* comes nearer  
 to us, sometimes goes further from  
 us; the Reason of which, is, be-  
 cause the *Moon* does not move in a  
 circular Orbit, which has the *Earth* for its Center:  
 But the real Orbit of the *Moon* is of an Elliptick  
 Form, such as is represented in the Figure ABPD,  
 one of whose *Focus*'s is always the Center of the  
*Earth*; AP is the greater *Axis* of the Ellipse, and  
 the Line of the *Apsides*; TC is the Excentricity; the  
 Point A, which is the highest *Apsis*, is called the *Apo-  
 geon* of the *Moon*; the lowest *Apsis*, which is the  
 Point P, is called the *Perigeon*, in which the *Moon*  
 comes nearest the *Earth*. And if the Orbit of the  
*Moon* had no other Motion besides that where-  
 with it is carried round the *Sun*, it would always  
 retain











retain a Position parallel to itself, and would always point the same Way, and be observed in the same Point of the Ecliptick; and whenever the *Moon* came to that Point, it would constantly be at the same Distance from us: But this Line of the *Apsides* is likewise observed to be moveable, and to have an angular Motion round the *Earth* from the *West* towards the *East*, according to the Order of Signs; so that it does not return to the same Situation, till after the Space of almost nine Years.

THE Motions of the *Moon*, and that of her Orbit, do not observe the same Inequalities. For, *First*, When the *Earth* is in her *Aphelion*, at the greatest Distance from the *Sun*, the *Moon* being so likewise, the *Moon* does somewhat quicken her Pace, and performs her Circulation in less Time. On the contrary, when the *Earth* approaches nearest to the *Sun* in the *Perihelion*, the *Moon* is likewise nearer, and then she slackens her Motion: Upon which Account it is, that the *Moon* revolves about the *Earth* in shorter Time, when the *Earth* is in her *Aphelion*, than when she is in her *Perihelion*; so that the periodical Months are not all equal.

*Secondly*, When the *Moon* is in the *Syzygia*, that is, in the Line which joins the Centers of the *Earth* and *Sun*, (which may be either in her Opposition or Conjunction) all other Things being alike, she has a swifter Motion round the *Earth*: But in the *Quadratures* she goes slower.

*Thirdly*, According to the different Distance of the *Moon* from the *Syzygia*. that is, from Opposition or Conjunction, she changes her Motion; and in the first Quarter of her Motion, that is, from Conjunction to her first Quadrature, she loses something of her Swiftness: In her second Quarter, from the Quadrature to her Opposition, she increases in Velocity: In her third Quarter, from Opposition to the last Quadrature, she again loses of her Motion; and from that Quadrature to the Conjunction, she again recovers her Swiftness. This Inequality in



Lecture the *Moon's* Motions was first discovered by the noble  
 X. *Tycho*, who called it the *Moon's Variation*.

*The Variation.* *Fourthly*, The *Moon* moves in an Ellipse, whose *Focus* is in the Center of the *Earth*, round about which she describes *Area's* proportional to the Times, as the primary *Planets* do round the *Sun*; whence the Motion of the *Moon* must be quickest in the *Perigeon*, and slowest in the *Apogee*.

*The Orbit of the Moon, and its Excentricity, changeable.* *Fifthly*, The very Orbit of the *Moon* is changeable, and does not always keep the same Figure; but its Excentricity does now and then grow greater, and now and then it diminishes: And it is greatest, when the Line of the *Apsides* is coincident with the *Syzygia*, or is in the Line which joins the Centers of the *Sun* and *Earth*: And the Excentricity is the least, when the Line of the *Apsides* cuts the other at right Angles. The Difference between the greatest and least Excentricity is so considerable, that it exceeds the half of the least Excentricity.

*The Apogee has an unequal Motion.* *Sixthly*, The very *Apogee* of the *Moon* has an unequal Motion, and sometimes moves forward, and sometimes backwards; when it is coincident with the *Syzygial* Line, its Motion is forward; but when it cuts that Line at right Angles, its Motion is backwards, and its Progress and Regress are no ways equal. But when the *Moon* is in her Quadratures with the *Sun*, the *Apogee* goes but slowly forward, or even may stand still, or go backwards. But when the *Moon* comes to be opposite or conjoined to the *Sun*, the *Apogee* has a quick Motion forward.

*Seventhly*, The Motion of the *Nodes* is not at all uniform; for when the Line of the *Nodes* coincides with the Line of the *Syzygia*, then they stand still without any Motion; but when they cut that Line at right Angles, they go backwards, or from *East* to *West*, with a considerably quick Motion. The most sagacious Sir ISAAC NEWTON was the first, and the only Man, who has discovered the true Causes of all these  
 Ine-



Inequalities; and has demonstrated, that they all arise, according to the Laws of Mechanism, from the *Theory of Gravitation* of Matter to Matter. It is very surprising, that the *Moon*, which of all the heavenly Bodies is nearest to us, should be of such difficult Access; and that it should be so hard to find out her Ways, and the Causes of all her Irregularities. Lecture X.

THE only equal Motion of the *Moon* is that wherewith she turns round her *Axis* in the same Time that she moves round us in her Orbit; from whence it comes to pass, that she always keeps the same Face towards us. But this very Equability in Rotation is the Cause of an apparent Inequality; that the *Moon* appears to librate about its *Axis* sometimes from the *East* to the *West*, and now and then from the *West* to the *East*; and that some Parts in the *Western* Limb or Margin of the *Moon* recede from the *Center* of the Disk, and sometimes they move towards it. Some of these Parts, which were before visible, set and hide themselves in the invisible Side of the *Moon*, and afterwards become again conspicuous. Such a Motion in the *Moon* is called her *Libration*, and it arises from the unequal Motion of the *Moon* in the Perimeter of her Orbit: For if the *Moon* moved in a Circle, whose Center coincided with the Center of the *Earth*, and turned round its *Axis* in the precise Time of its Period round the *Earth*, in that Case the Plane of the same *Lunar* Meridian would always pass thro' the *Earth*; and the same Face of the *Moon* would be constantly and exactly turned towards us. But since the real Motion of the *Moon* is in an Ellipse, in whose *Focus* is the *Earth*, and the Motion of the *Moon* about her *Axis* is equable; or, which is the same Thing, every Meridian of the *Moon* by this Rotation describes Angles proportional to the Times, the Plane of no one Meridian will constantly pass through the *Earth*.

*The Moon moves uniformly about her Axis.*

*The Moon's Libration.*



Lecture  
X.

Plate VI.  
Fig. 2.

FOR let ALP be the Orbit of the *Moon*, in whose *Focus* is the *Earth* in T; and when the *Moon* is in A, its Meridian MN produced, will pass thro' the *Earth*: And if the *Moon* only revolved in her Orbit, without any Motion round an *Axis*, the same Meridian MN would always keep a Position parallel to itself; so that when the *Moon* comes to L, the Meridian MN would be in the Position PQ, which is parallel to MN; but on the Account of the *equable Rotation*, the Meridian MN changes its Situation, and describes Angles proportional to the Times; so that in the periodical Time of the *Moon's* Revolution round the *Earth*, it describes four right Angles; and therefore in L it will have the Position mLn; such that the Angle QLn may have the same Proportion to a right Angle, as the Time the *Moon* takes to describe the Arch AL has to a fourth Part of the periodical Time. But the Time the *Moon* takes to describe the Arch AL is to the fourth Part of the periodical Time, as the *Area* ATL is to the *Area* ACL; that is, to  $\frac{1}{4}$  Part of the *Area* of the Ellipse: Therefore the Angle QLn will be to a right Angle in the same Proportion. But the *Area* ATL is greater than the *Area* ACL, or than the fourth Part of the *Area* of the Ellipse: The Angle therefore QLn will be bigger than a Right, or bigger than QLC: but QLC is bigger than QLT; wherefore QLN will be much bigger than QLT. The Meridian therefore MN, whose Plane passed thro' the *Earth*, when the *Moon* was in A, now the *Moon* is arrived at L, does not look towards the *Earth*: And therefore the Hemisphere of the *Moon* which is towards the *Earth*, the *Moon* being at L, is not the same with that which was towards the *Earth* when the *Moon* was in A; and those Parts of the *Moon's* Surface beyond Q will come under Observation, which before, when the *Moon* was in A, were not to be seen, being in the Side of the *Moon* quite opposite to us. But as soon as the

*Moon*



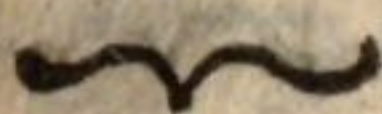
*Moon* arrives at her *Perigeon* P, then the Meridian MN has described in its Rotation a Semicircle; and then again its Plane passes thro' the *Earth*, and the former Point N will be directly towards us, and be in the Center of the Disk. Hence it is evident, that this *Libration* of the *Moon* is restored twice in each Period of the *Moon*, that is, when she comes to her *Apogee* and *Perigeon*.

IF the Surface of the *Moon* were smooth and polished like a Looking-glass, it would not then reflect Light upon all Sides, and every way; but it would shew us only in some Positions the Image of the *Sun*, no bigger than a Point, but with an immense Lustre. But as in all our *Earthly* Bodies, so in the *Moon*, its Surface is very rough and uneven; upon which Account it diffuses the Light by reflecting it to all Sides, without producing any Image of the *Sun*, as polished Glasses do.

BUT the Surface of the *Moon* is not only rough and uneven, but there are upon it most prodigious high Mountains, and deep Vallies, which cover the whole Face of the *Moon*: This we thus prove. If there were no Parts in the *Moon* higher than the rest, no prominent Points, then a Right Line in the *Dichotomy* or *Quadrature*, and an Elliptick Line in all the other *Phases*, would terminate the light and dark Parts of the Disk: But when the *Moon* is viewed with a Telescope, we find that there is no regular Line, which separates Light and Darkness in the *Moon's* Surface; but the Confines of these Parts appear, as it were, toothed, and cut with innumerable Notches and Breaks; and even in the dark Part, near the Borders of the lucid Surface, there are seen some small Places enlightened by the *Sun's* Beams: And upon the fourth Day after *New Moon*, there may be perceived some shining Points, like Rocks or small Islands, within the dark Body of the *Moon*; but not far from the Confines of Light and Darkness, there are observed other little Spaces, which join to the enlightened



Lecture  
X.



lightened Surface, but run out into the dark Side; which by Degrees change their Figure, 'till at last they come wholly within the illustrated Face, and have no dark Parts round them. Afterwards we observe many more shining Spaces to arise by Degrees, and to appear within the dark Side of the *Moon*, which, before they drew near to the Confines of Light and Darkneſs, were inviſible; being without any Light, but wholly immerſed in the Shadow. The contrary is obſerved in the decreaſing *Phaſes*, where the lucid Spaces which joined the illuminated Surface, by Degrees recede from it; and after they are ſeparated quite from the Confines of Light and Darkneſs, remain for ſome time viſible, 'till at laſt they alſo diſappear: Now it is impoſſible, that this ſhould be, unleſs theſe ſhining Points were higher than the reſt of the Surface, ſo that the Light of the *Sun* may reach them.

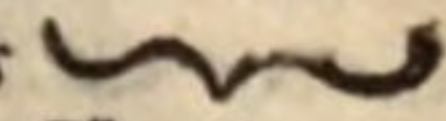
*In the Moon  
large Cavi-  
ties and Pits.*

THESE ſhining Points ſituated in the *Moon's* Surface, without the Confines of the illuminated Surface, are the Tops of very high Mountains, which riſing far above the other Parts of the Surface, are ſooner reached by the *Sun's* Beams, and remain longer in the Light, than the reſt of the Parts do which are lower. Beſides theſe, we likewiſe obſerve, even in the illuminated Face of the *Moon*, many dark and obſcure Spots, which ſeem to be only Caverns, or large Cavities; on which the *Sun* ſhining very obliquely, and touching only their upper Edge with his Light, the deeper Places remain without Light: But as the *Sun* riſes higher upon them, they receive more Light, and the Shadow or dark Parts, grow ſmaller and ſhorter, 'till the *Sun* comes at laſt to ſhine directly upon them; and then the whole Cavity will be illuſtrated, and the Parts which were obſcure before, will then look as bright as the Tops of the Mountains. From theſe conſtant Obſervations, it is plain to a Demonſtration, that the *Moon's* Face is covered with Mountains in ſome Places, and that in others it is cut with deep Pits and Caverns.

THE



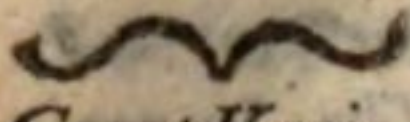
THE *Lunar* Mountains are much higher in Lecture Proportion to the Body of the *Moon*, than any Mountain upon our Globe; for the *Geometers* X.

can take the Height of them, as easily as they can find the Measure of a Mountain upon our *Earth*. *The Lunar Mountains higher than the Mountains of the Earth.*  *Plate VI. Fig. 3.*

The Way of finding the Height of a *Lunar* Mountain is this: Let  $E G D$  be the Hemisphere of the *Moon* illuminated by the *Sun*, and  $E C D$  the Diameter of the Circle, bounding Light and Shadow,  $A$  the Top of a Hill, within the dark Part, when it first begins to be illuminated. Observe with a Telescope the Proportion of the Right Line  $A E$ , or the Distance of the Point  $A$ , from the lucid Surface, to the Diameter of the *Moon*  $E D$ ; and because in this Case the Ray of Light  $E S$  touches the Globe of the *Moon*,  $A E C$  will be a Right Angle, by the 16th Prop. Book Third, of *Euclid*: And therefore having in the Triangle  $A E C$ , the two Sides  $A E$  and  $E C$ , we can find out the third Side  $A C$ , from which subtracting  $B C$ , or  $E C$ , there will remain  $A B$ , the Height of the Mountain. *Ricciolus* affirms, that upon the fourth Day after *New Moon*, he has observed the Top of the Hill called *St. Katharine* to be illuminated, and that it was distant from the Confines of the lucid Surface, about a sixteenth Part of the *Moon's* Diameter, or an eighth Part of her Semidiameter. And therefore, if  $C E$  be 8,  $A E$  will be 1; and the Square of  $A C$  will be equal to the Squares of  $C E$  and  $E A$ , by Prop. 47, Book First, of *Euclid*. Now the Square of  $C E$  being 64, and the Square of  $A E$  being 1, the Square of  $A C$  will be 65, whose square Root is 8,062 which expresses the Length of  $A C$ : From whence deducting  $B C = 8$ , there will remain  $A B = 0,062$ . So that  $C B$  or  $C E$  is therefore to  $A B$ , as 8 is to 0,062; that is, as 8000 to 62: And therefore, since the Semidiameter of the *Moon* is 1182 Miles, if we make the Proportion as 8000 to 62, so 1182 is to 9; we shall have 9 Miles for the Height of that Mountain, which



Lecture which is therefore three times higher than the  
 X. Tops of our highest Hills on *Earth*.

*Great Varieties to be observed in the Face of the Moon.*  WHOEVER shall contemplate the Face of the *Moon* with a Telescope, will discern it distinguish'd with an admirable Variety of Spots; some Parts have a most bright Lustre, and some *Philosophers* have imagined them to be Rocks of Diamonds; others have compared them to Pearls, or some precious Stones: But they seem to be the solid Parts of high Mountains, which are endued with a Quality whereby they strongly reflect the Light. There are again other Places and Parts of the *Moon's* Face, and they are not a few nor small, which look dark, and of a dusky Colour, which the *Philosophers* have fancied to be Seas, Lakes, and Fens: But yet we find, that they cannot be Seas, nor any thing of a liquid Substance; for when they are looked at with a good Telescope, we find they consist of an Infinity of Caverns and empty Pits, whose Shadows fall within them; which can never be in a Sea or liquid Body. These black Spots therefore cannot possibly be Seas: But they consist of some darker and sad-coloured Matter, which does not reflect the Light so strongly, as the solid and shining Mountains do. But even within these dark Spots, we observe some Bodies of a brighter Light, wherewith they outshine the rest.

*There are no Seas.*

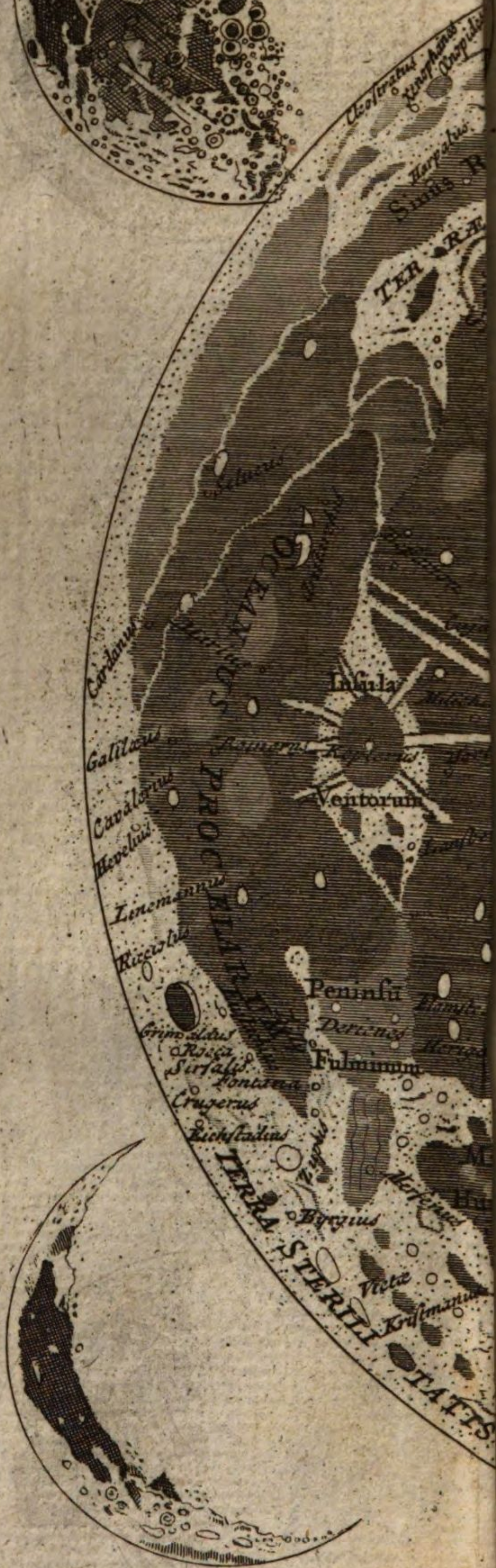
*No Clouds.* THERE seem to be no Clouds nor Vapours in the *Moon*, from whence Rain may be generated: For such Clouds would sometimes cover the Face of the *Moon*, and hide some of its Regions from our Sight, which we never observe them to do: But in the *Moon* there is a constant Serenity, without any dark Weather; and when there are no Clouds in our Air, the *Moon* constantly appears with the same Lustre. It is probable likewise, that the *Moon* has no Atmosphere to surround it: For the *Planets* and *Stars*, which sometimes are seen very near its Limb, have not their Light refracted, as it is when it passes thro' our Atmosphere.

THE

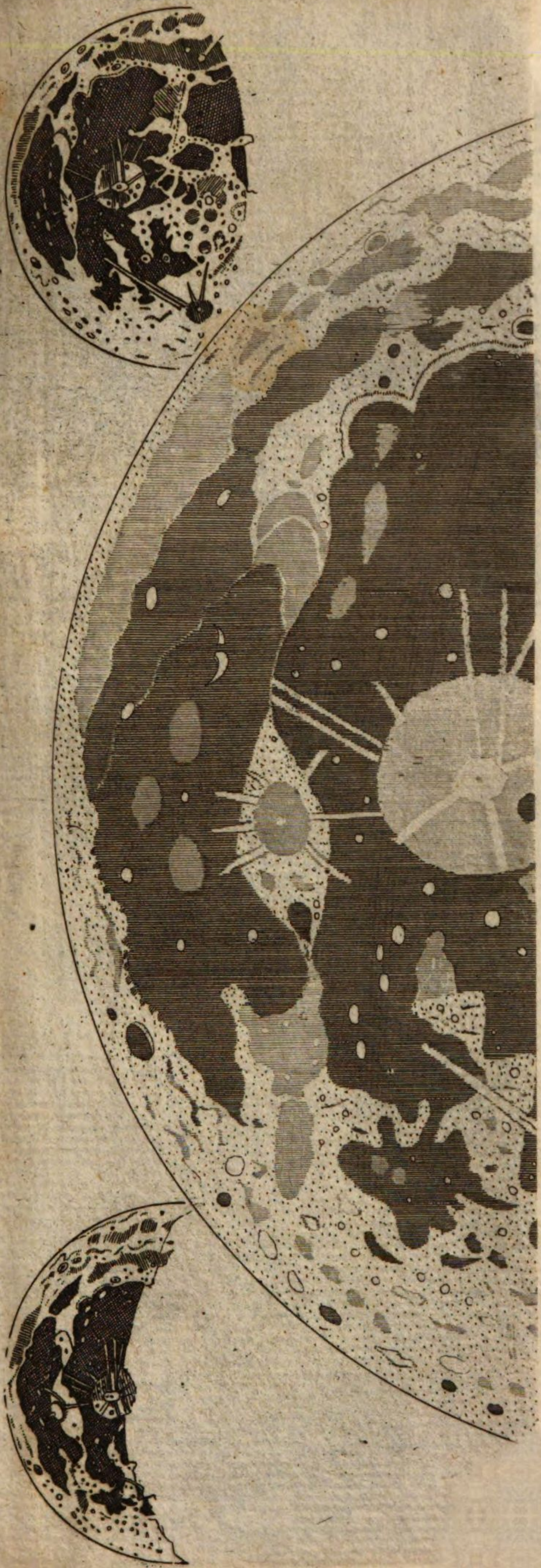










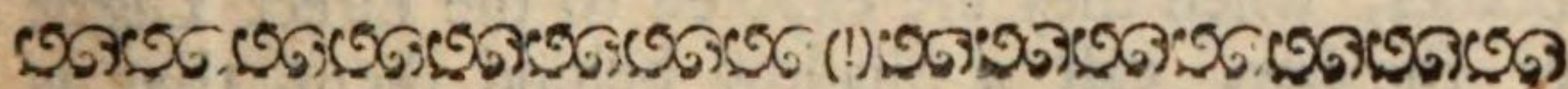








THE *Astronomers* have drawn the Face of the *Moon*, according as it is seen with the best Telescopes; for which we are obliged to the accurate Labours of these famous Selenographers *Florentius*, *Langrenus*, *John Hevelius* of *Dantzic*, *Grimaldus* and *Ricciolus*, *Italians*; who have taken particular Care to note all the shining Parts of the *Moon's* Face, and for the better distinguishing them, they have given to each Part a proper Name. *Langrenus* and *Ricciolus* have divided the *Lunar* Regions among the *Philosophers* and *Astronomers*, and other eminent Men: But *Hevelius*, fearing lest the *Philosophers* should quarrel about the Division of the Lands, has spoiled them of this their Property, and gives the Parts of the *Moon* those *Geographical* Names, that belong to the different Islands, Countries and Seas of our *Earth*, without any Regard to Situation or Figure.

Lecture  
XI.The Seleno-  
graphers or  
Astrono-  
mers who  
have de-  
scribed the  
Moon's  
Surface.

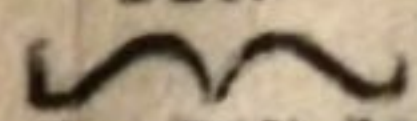
## LECTURE XI.

Of the Obscurations or Eclipses of the  
Sun and Moon.

HERE is nothing in *Astronomy*, which shews the great Sagacity of human Understanding, and its deep Penetration more, than a clear Explication of the sudden Disappearings of the *Sun* and *Moon*, that is, of their *Eclipses*; and the accurate Predictions when they are to come to pass, which the *Astronomers* can now foretel almost to a Minute. Tho' this be the nicest and most subtle Speculation of our Science, yet it is certain and undoubtable, than which nothing can



Lecture can be more sublime, or worthy of our Contem-  
 XI. plation.

 THE Word *Eclipse* is derived from the *Greek*  
*An Eclipse*, ἐκλείπω, which signifies to faint, or to swoon  
*what.* away: So sick and dying Persons, when a swoon-  
 ing Fit, and a death-like Faintness comes over  
 them, were said by the *Greeks* to fall into an  
*Eclipse*: After the same Manner the *Moon*, when  
 she shines with a full Face, if she falls into the  
 Shadow of the *Earth*, does lose the enlivening  
 Beams of the *Sun's* Light, and grows pale, as if she  
 were about to die. And the *Sun* again, when the  
*Moon* interposes her Body, and deprives us of his  
 Heat and Light; tho' in himself he retains his  
 Lustre, yet to us he seems to vanish and grow  
 dark. At such Times the *Sun* and *Moon* are said  
 to suffer, and fall into an *Eclipse*. These *Eclipses*  
 must be here explained: And, that we may begin  
 from the first Principles;

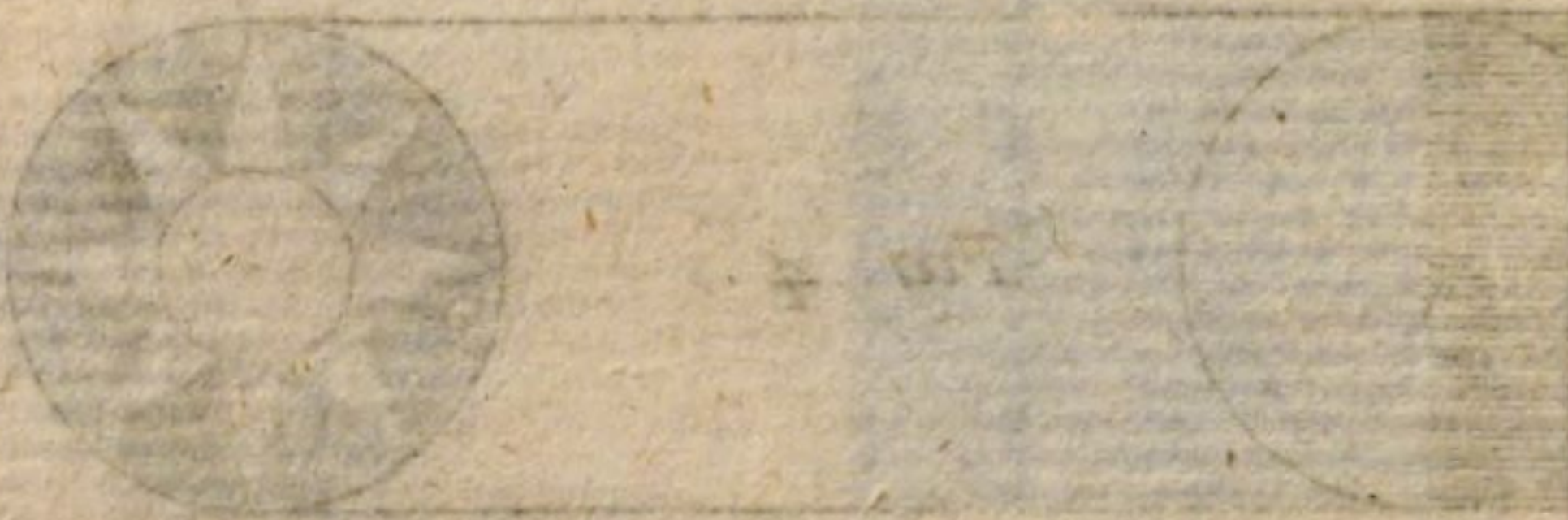
*A Shadow,* IT is to be observed, that all opaque and dark  
*what.* Bodies, when they are exposed to the direct Light  
 of the *Sun*, cast a Shadow behind them, that is  
 opposite to the Line the *Sun* is in. This Shadow  
 is nothing but the Loss or Privation of Light, in  
 the Space opposite to the *Sun*, by reason the *Sun's*  
 Rays are intercepted by the opaque Body. Now  
 since the *Earth* is an opaque Body, it must likewise  
 cast a Shadow towards the Space opposite to the  
*Sun*; in which Space if the *Moon* should come, it  
 must necessarily be darkened, and lose the Light  
 which it had before from the *Sun*. And because  
 Plate VI. Fig. 4, 5, 6. the Figure of the *Earth* is Spherical, the Figure  
 of the Shadow would be Cylindrical, if the *Earth*  
 and *Sun* were of equal Bigness; or if the *Earth*  
 were bigger than the *Sun*, the Shadow would have  
 the Figure of a Cone, which had lost a Piece at his  
 Top or Vertex; and the farther it were extended,  
 would grow thicker and thicker.

*The Figure* AND in both these Cases, the Shadow would  
*of the Sha-* run out into infinite Space, without ever having  
*adow.* an End: And then it would involve sometimes  
 the other *Planets*, *Mars*, *Jupiter* and *Saturn*, with-  
 in











in it, when they come to be opposite to the *Sun*, and enter within that Space: But this is never observed, for then these *Planets* would be eclipsed: And therefore the *Sun* must necessarily be greater than the *Earth*, whose Shadow must consequently be of a conical Figure, and end in a Point.

Lecture  
XI.

*The Sun  
bigger than  
the Earth.*

BUT the *Moon*, since its Diameter is contained about three times in the Diameter of the Shadow, and the Diameter of the Shadow is less than that of the *Earth*, must needs be much less than our *Earth*.

LET S represent the *Sun*, T the *Earth*, and the Cone ABC the Shadow. It is evident, there can be no Line drawn from the *Sun*, to any Point of the Space ABC, which does not fall upon the *Earth*: And therefore, since the *Earth* is an opaque Body, it will not suffer any Rays to pass through, or to illustrate the Space ABC. Now if the *Moon*, when she is opposite to the *Sun*, should come into this Space, she must then be involved in Darkness; and would then suffer an Eclipse in the very Time of Full Moon.

Plate VI.  
Fig. 7.

THE *Moon* likewise, upon the same Account, must have a Shadow of a conical Figure opposite to the *Sun*; and if this Shadow should fall upon the *Earth*, which can never happen, but when the *Moon* is in Conjunction with the *Sun*, the Inhabitants of the *Earth*, on whom the Shadow falls, will be involved in Darkness; and the *Sun* will seem to them to be in an Eclipse, so long as the Shadow covers them; but because the *Moon* is much less than the *Earth*, its Shadow can never cover the whole *Earth*, but only a small Part of it, such as BC: And within that Space only, where the Shadow comes, there will be total Darkness; and the rest of the circumjacent Places will be illustrated with some of the *Sun*'s Beams, and their Inhabitants will only see a Part of the *Sun*'s Disk obscured; which will be greater or less, according as they are nearer or further removed from the Shadow:

*When there  
can happen  
an Eclipse of  
the Moon.*

Plate VII.  
Fig. 1.



Lecture XI. Shadow: Particularly, they who live about P, will see half the *Sun* eclipsed; but whosoever lives between M and N, will see at the same time all the *Sun's* Body, and perceive no Eclipse.

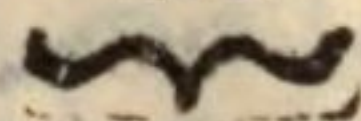
In some Places of the Earth an Eclipse may be total, in others partial, and in others none at all.

When an Eclipse of the Sun happens.

HENCE it is manifest that there can be no Eclipse of the *Moon* but in *Full Moons*, when she is opposite to the *Sun*; as the Shadow always is. Nor can there be any Eclipse of the *Sun*, but in *New Moons*, when she is in Conjunction with the *Sun*; for then only she can cast her Shadow on the *Earth*. Since therefore in every Month there is one *Full Moon*, and one *New Moon*; it may be asked how it comes that the *Sun* and *Moon* do not suffer Eclipses every Month. And indeed if the *Moon* did always move in the Plane of the Ecliptick, since the *Axis* of the Shadow is always in the same Plane, the *Moon* would then every *Full Moon* pass through the Body of the Shadow, and there would be a total Eclipse of the *Moon*. So likewise in every *New Moon*, if she were not then too far off us, she should cast her Shadow on the *Earth*, and produce an Eclipse of the *Sun*, in some or other of the Regions of the *Earth*. But the Case is otherwise; for we have shewed, that the Plane of the *Moon's* Orbit does not coincide with the Plane of the Ecliptick; but that it cuts it in a Line which passes thro' the Center of the *Earth*: And therefore the *Moon* is never in the Plane of the Ecliptick, but when it is in this Line, which is the Intersection of the two Planes, that is, when it enters the *Nodes*. And therefore, when it happens, that the *Moon* at *Full* shall likewise be in one of the *Nodes*; then the *Axis* of the Shadow will pass through the Center of the *Moon*, and then she will be in a total and central Eclipse. Let the Circle MN represent the transverse Section of the Shadow, at the Distance of the *Moon*; and the Line CD a Portion of the Orbit of the *Moon*; which the *Moon* describes in the Time of *Full Moon*; which, because it is but a small Portion, may be well enough represented by

Plate VII.  
Fig. 2.  
Total and central  
Eclipses of  
the Moon.





by a right Line: Let the right Line BGA be in the Plane of the Ecliptick, and let F be the Position of the *Moon's* Center, when she first touches the Shadow; E the Position of the same Center, when she first leaves it; G the same Center of the *Moon*, when the *Axis* of the Shadow passes through it: It is evident, that such an Eclipse will be Central and Total; and there will always be such Eclipses, when the Center of the *Moon*, and *Axis* of the Shadow, meet in the *Nodes*. Hence the Duration or Time that an Eclipse can last, may be as long as the *Moon* is passing through an Arch, that is, equal to EF, or four Diameters of the *Moon*; that is, about two Degrees, which Space the *Moon* generally moves through in the Space of four Hours.

BECAUSE of the Largeness of the Diameter of the Shadow in Comparison of that of the *Moon*, there may be total Eclipses, which are not central, where the *Node* does not coincide with the *Axis*; and may even lie without the Shadow, as the Figure Plate VII. sufficiently shews. The *Node* may likewise be at Fig. 3. such a Distance from the Shadow, that there may be only a Part of the *Moon's* Body that can enter it; and then we shall have a partial Eclipse of the *Moon*, Partial Eclipses. as is manifest by the Figures; and these partial Eclipses will be greater or less, according as the Distance of the *Node* from the Shadow is less or greater. Plate VII. Fig. 4, 5. But when it happens that the *Node*, in the Time of *Full Moon*, is further removed from the *Axis* of the Shadow than twelve Degrees, the *Moon* then will have so much Latitude, or its Distance from the Ecliptick will be so great, that it cannot be obscured by the Shadow.

As the Shadow of the *Earth* cast upon the *Moon* produces an Eclipse of the *Moon*, so, if the Shadow of the *Moon* should fall upon the *Earth*, it will cause an Eclipse of the *Earth*, at least on that Part of the *Earth* on which the Shadow falls. For the *Moon* being much less than the *Earth*, cannot with its Shadow involve the whole Disk of the *Earth*, but only a very small Part of it; and so all the Eclipses of the *Earth* will be Partial, and not Total; and



Lecture and such Eclipses will only produce a Darknefs upon  
 XI. those Places where the Shadow falls ; and the Inha-  
 bitants within this Shadow will only see the *Sun* to-  
 tally darkened, and therefore they will call them  
 Eclipses of the *Sun* : But this is improperly attributed  
 to the *Sun*, who all the Time retains his Light  
 without the least Diminution ; and it is only those  
 Inhabitants of the *Earth* that are under the Shadow,  
 that are truly eclipsed, and involved in Darknefs.

*Lines drawn  
 from the  
 Center of the  
 Sun to any  
 Point of the  
 Earth, may  
 be reckoned  
 as parallel.*

THAT we may descend more particularly to ex-  
 plain the Phænomena or Appearances of Eclipses ;  
 it will be requisite to shew the Method of measur-  
 ing the Dimensions of the conical Shadows of both  
*Earth* and *Moon* : For which Purpose we will first  
 lay down the following *Postulatum* : If from the  
 Center of the *Sun*, there be drawn right Lines to  
 every Point of the *Earth*, or to as many as you  
 please, these Lines may all of them be esteemed as  
 parallel. For parallel Lines are such as do not meet,  
 till they are produced to an infinite Distance ; and  
 therefore such Lines as do not meet but at a Di-  
 stance immensely great, in Comparison of the Di-  
 stance of the Lines from one another, are nearly,  
 or, as we may say, physically parallel ; that is to say,  
 they will have the same Effect in Nature, and the  
 physical Observations that are to be made from  
 them, will be the same, as if the Lines were abso-  
 lutely parallel. Now the Distance of the *Earth*  
 from the *Sun* is so great, that the Diameter of the  
*Earth*, compared with it, is but as a Point, as is  
 now acknowledged by all Mathematicians ; for this  
 Diameter, seen from the *Sun*, does appear under an  
 unperceptible Angle, or which is so small, that the  
 Eye cannot observe it, and the *Earth* appears only  
 like a Point : And therefore in Comparison of the  
 great Distance of the *Sun*, it vanishes ; and conse-  
 quently Lines drawn from the Center of the *Sun*  
 to different Parts of the *Earth*, will be at least phy-  
 sically parallel. Moreover it is known in Geome-  
 try, that if a right Line falls upon two other right  
 Lines, so as to make the two internal Angles on  
 the same Side equal to two right Angles, that these  
 two



two Lines on which it falls are parallel, by 29 *Prop.* Book First, of *Euclid*. Let therefore the Line AB, be the Diameter or Semidiameter of the *Earth*, and C the Center of the *Sun*; drawing AC and BC, the Angles A, B and C of the Triangle ABC are equal to two right Angles: Now the Angle C at the *Sun* vanishes, and is next to nothing; for the *Earth*, seen from the *Sun*, looks like a Point; and therefore the Angles at A and B must make by themselves two right Angles very nearly, and therefore the right Lines AC, BC, are nearly parallel. It is upon the same Account, that if there be taken two Threads with Plumbets to make them hang perpendicularly, the Directions of those Threads are by all Artificers esteemed as parallel, though their Directions will meet at the Center of the *Earth*, to which all heavy Bodies have a *Tendency* or *Propension*.

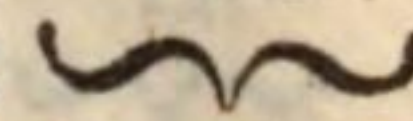


Plate VIII.  
Fig. 6.

WHAT we have said in this Case concerning the *Earth*, is also true of the *Moon*; for its Diameter has a much less Proportion to the Distance of the *Sun*, than that of the *Earth* has to it. And not only Lines drawn from the *Sun* to any Points of the *Earth* and *Moon*, are to be reputed parallel; but if there be two Lines drawn, one from the Center of the *Sun* to the *Earth*, the other from thence to the *Moon*, these may be likewise taken as Parallels; for they will not sensibly differ from a Parallelism, especially in the Time of Eclipses: The Difference of these Lines from real Parallels is so small, that it will make no sensible Error in the Calculation of Eclipses.

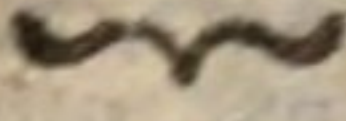
WE likewise premise the following *Lemma*, which is easily demonstrated:

IF two right Lines AE, BF, touch a Circle, and there be drawn from the Points of Contact to the Center the Lines AD, BD; the Angle at the Center contain'd under these Lines, will be equal to the Angle that the Tangents make with one another. For in the four-sided Figure GABD, all the Angles make four Rights: But the Angles A and B

Plate VII.  
Fig. 7.

A Lemma.



Lecture XI.  make two Rights, by the 18th *Prop.* Book Third, of *Euclid* : Wherefore the Angles  $AGB$  and  $D$ , are equal to two Rights. But by the 13th *Prop.* Book First of *Euclid*, the Angles  $AGB$  and  $EGB$ , are equal to two right Angles ; and therefore the Angles  $D$  and  $EGB$  are equal, since the Angle  $AGB$  makes two right Angles with either of them.

The Dimen-  
sion of the  
Angle of  
the Conical  
Shadow.  
Plate VII.  
Fig. 8.

LET the Circle  $ABK$  represent the Globe of the *Earth*,  $AM$  the Line which joins the Centers of the *Sun* and *Earth* ; to which let the Diameter  $CB$  be perpendicular : If from  $B$  there be drawn to the Center of the *Sun* the Line  $EF$ , this Line will be parallel to the Line  $CM$ , as has been shewn : Make the Angle  $BCD$  equal to the apparent Semidiameter of the *Sun* ; that is, equal to the Angle under which the Semidiameter of the *Sun* is seen from the *Earth*, and then through  $D$  draw the Tangent  $DG$ . By the *Lemma* above demonstrated, the Angle  $GEF$  will be equal to the Angle  $BCD$ , or to the apparent Semidiameter of the *Sun* ; and therefore, since the Line  $BF$  produced goes to the Center of the *Sun*, the Line  $GED$  must touch its Circumference, and it will also touch the *Earth*, and being produced, will meet with the *Axis* of the Shadow  $CH$  in  $H$ , so that the Angle  $DHC$  will be half the Angle of the conical Shadow. Now because  $EF$  is parallel to  $MH$ , the Angles  $DHC$  and  $GEF$  are equal, by the 29th *Prop.* Book First of *Euclid*. But  $GEF$  is equal, as has been shewed, to the apparent Semidiameter of the *Sun* ; wherefore the whole conical Angle  $KHD$  is equal to the apparent Diameter of the *Sun*.

These An-  
gles in all  
conical Sha-  
dows are  
equal.

THE same Thing is to be demonstrated of the *Moon*, and universally, the *Sun's* apparent Diameter remaining the same in all Spheres, which are not bigger than the *Earth* ; the Angles of the conical Figures which include the Shadows are all equal, and all their Shadows will be similar Figures. This may likewise be demonstrated in this Manner :

LET

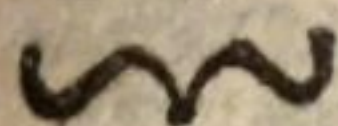


LET AGF be the *Sun*, DHE the *Earth*, SC a Line joining the Centers of the *Sun* and *Earth*, AD a right Line which touches both Bodies; and let the Lines AD, SC produced, meet in M; the Angle AMS will be half the Angle of the shadowed Cone. Now in the Triangle SDM, the outward Angle ADS is equal to both the inward and opposite Angles, by *Prop. 32. Book First of Euclid*; that is, the Angles DMS and DSM are equal to the Angle ADS; but the Angle DSM is nothing, or next to nothing, being the Angle under which the Semidiameter of the *Earth* appears as seen from the *Sun*; and the Angle ADS is the apparent Semidiameter of the *Sun*; therefore the Angle DMS, or the Semiangle of the Cone, is equal to the apparent Semidiameter of the *Sun*.

Plate VII.  
Fig. 9.







## LECTURE XII.

*Of the Penumbra and its Cone; the Height of the Shadow, and the apparent Diameters of the Shadows.*

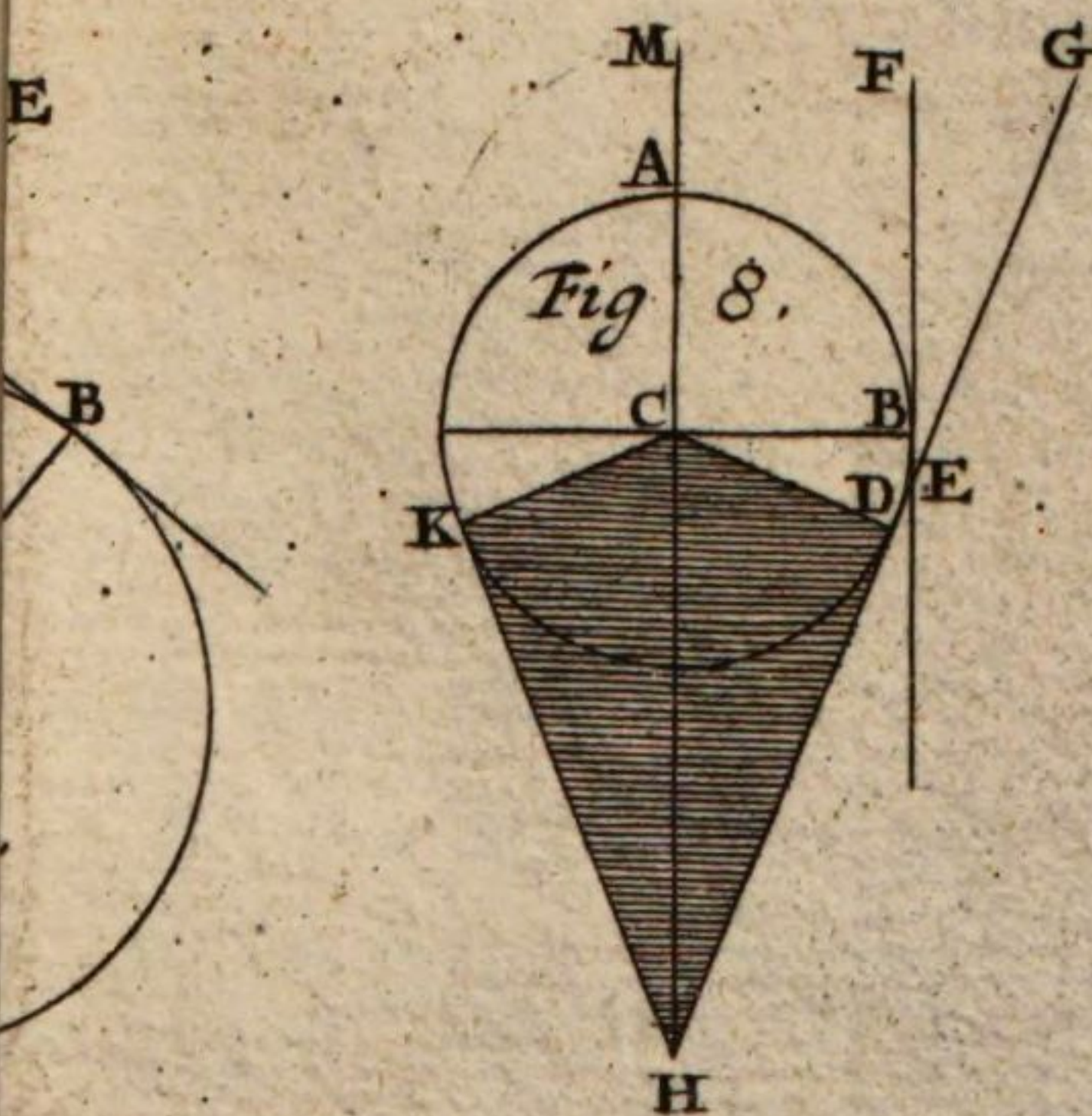
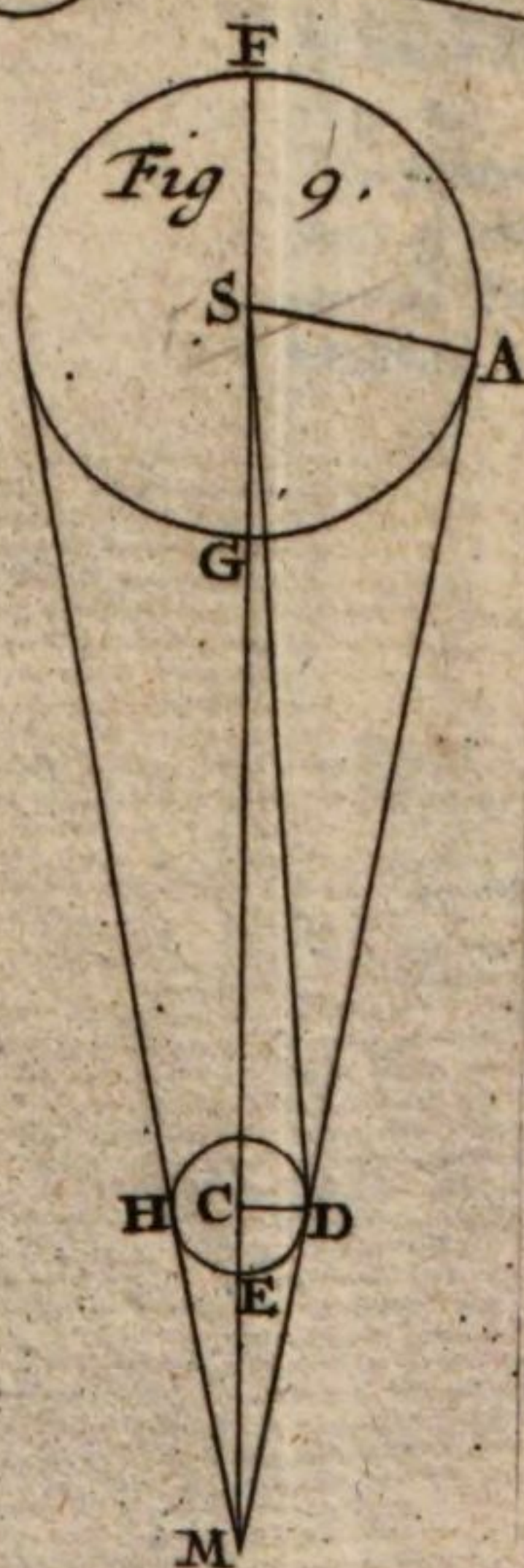
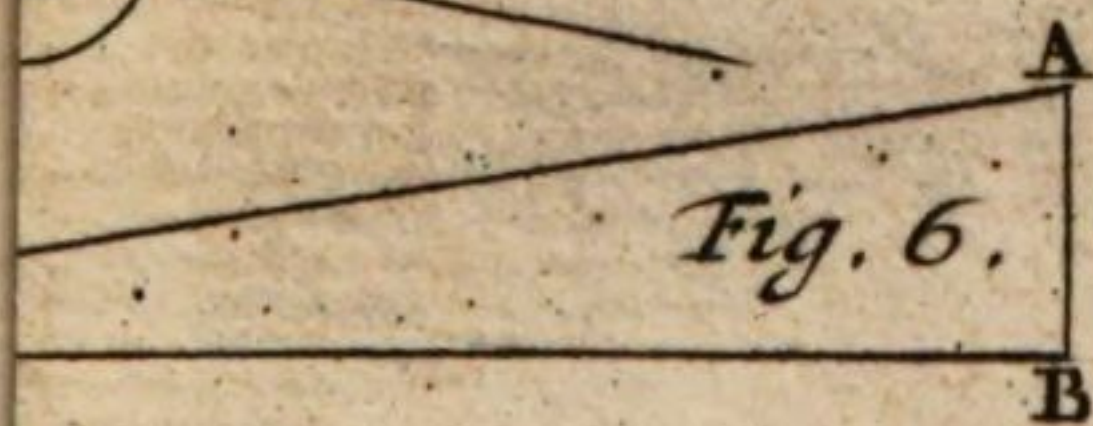
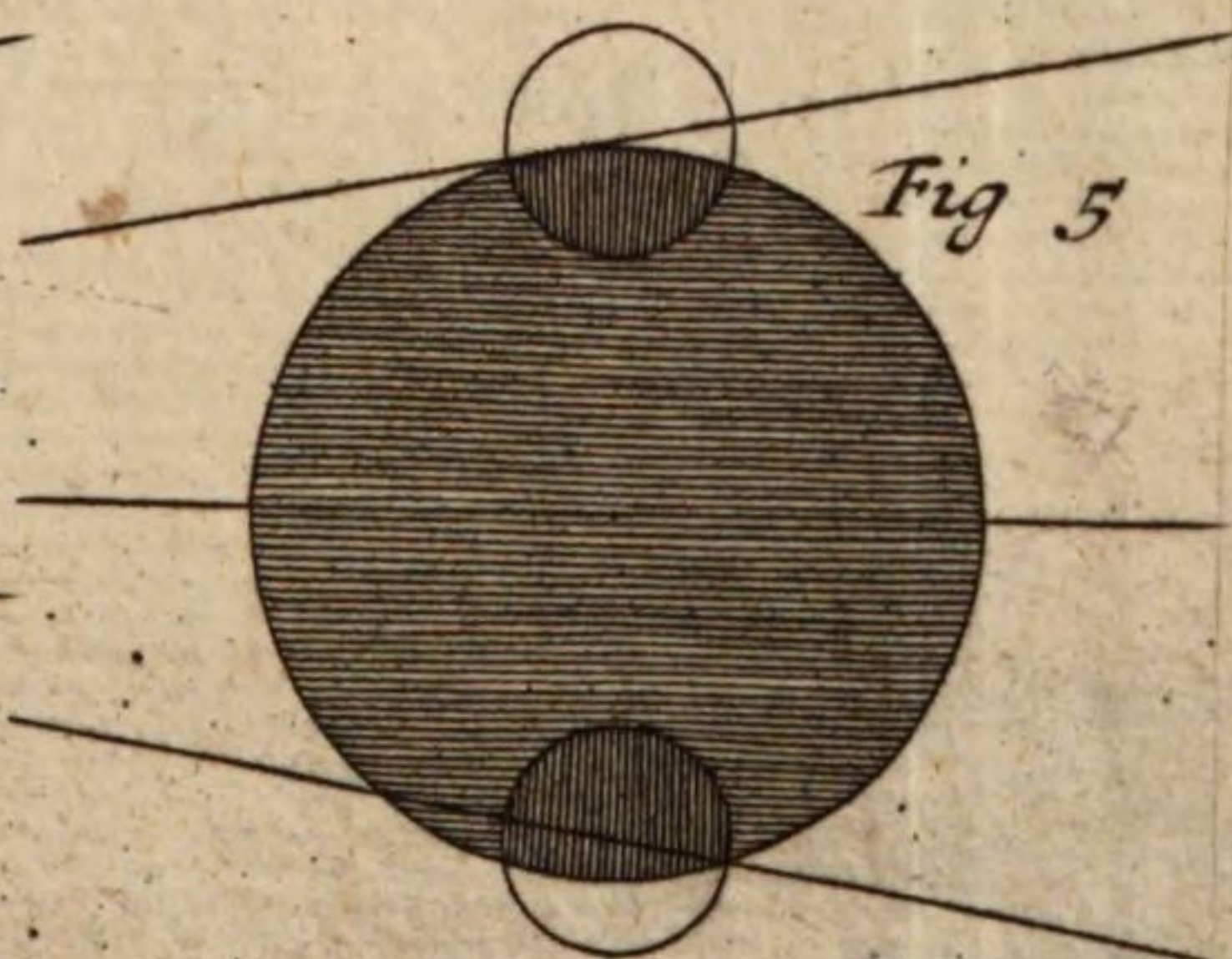
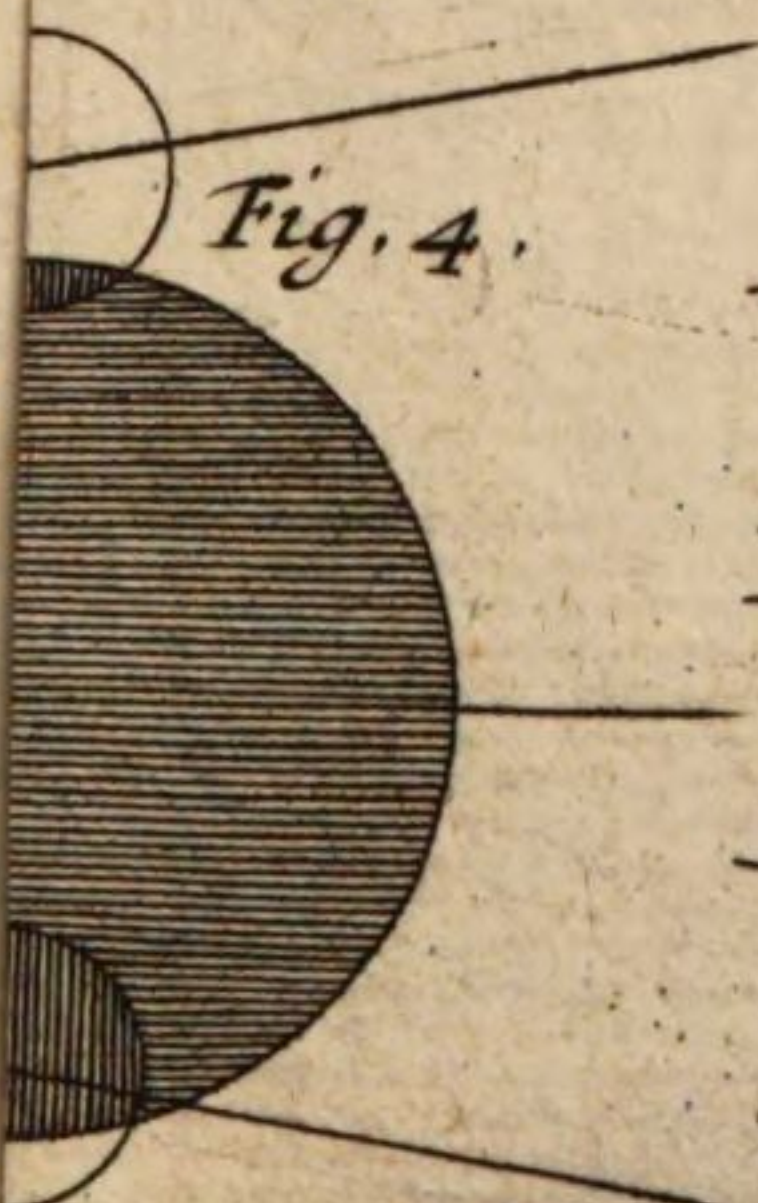
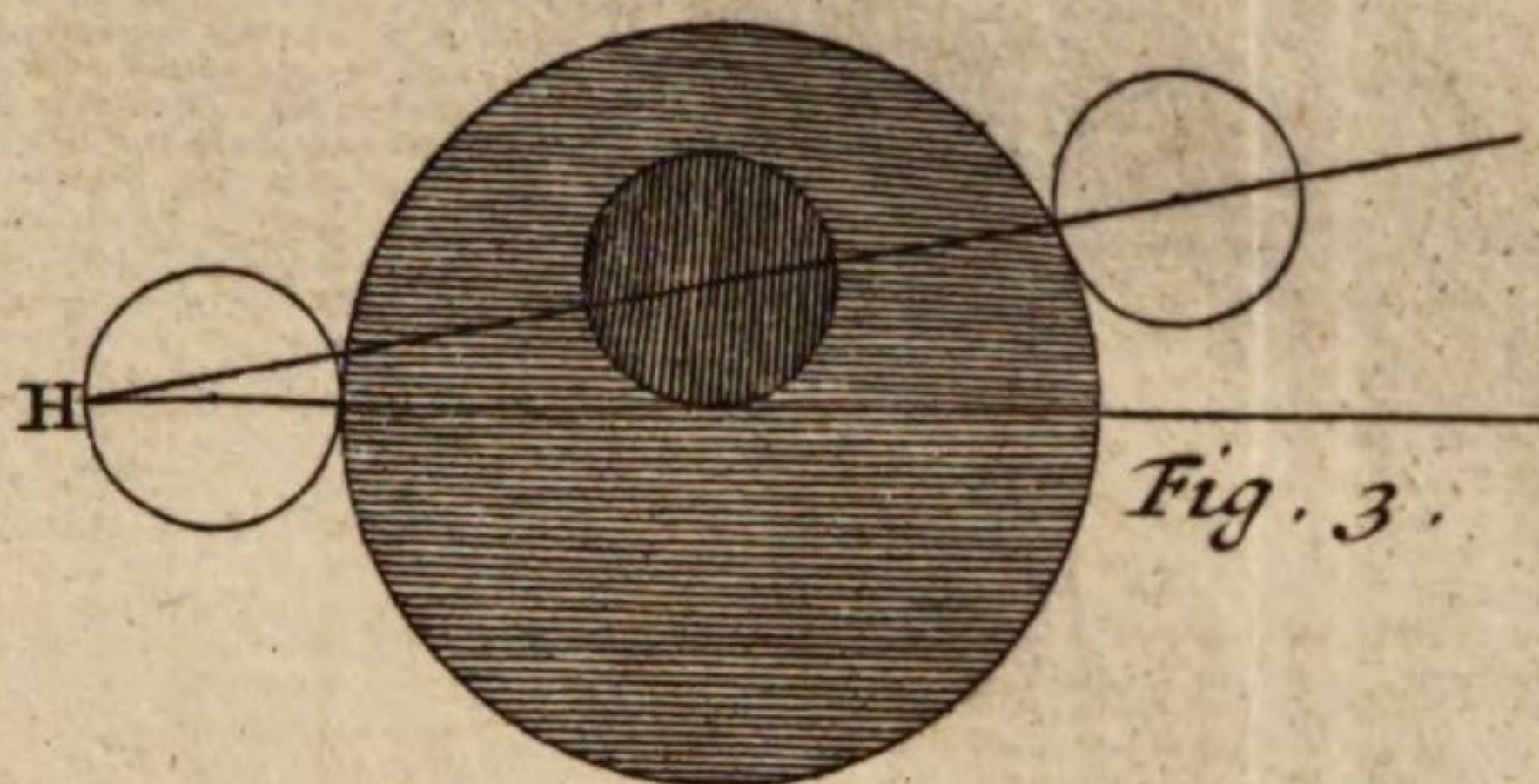
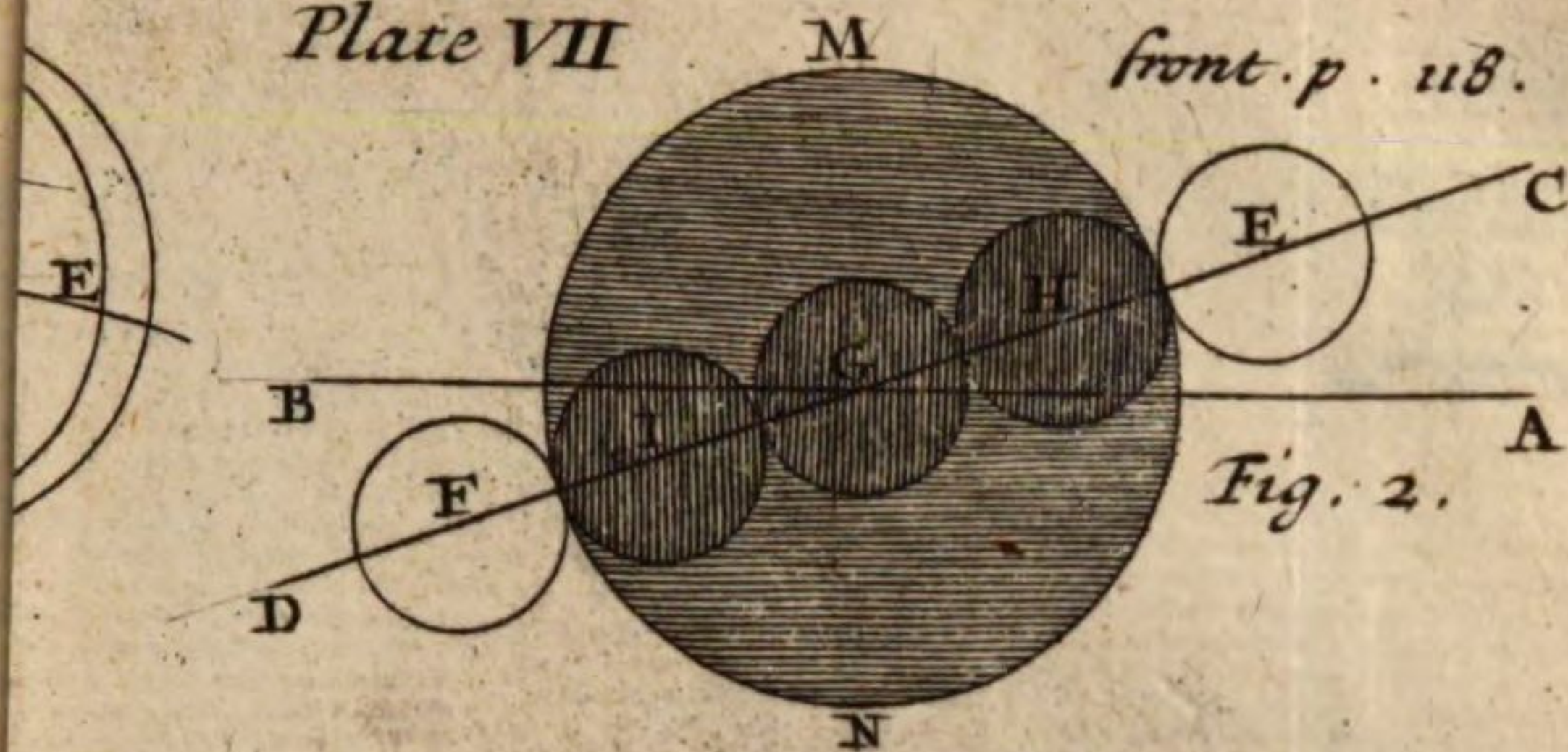


ESIDES the Shadow which is deprived of all the *Sun's* Light, there is a certain Space which is but a partial Shadow, and is called a *Penumbra*; for tho' all the *Sun's* Body does not illuminate it, there are, for all that, Rays coming from some Part of the *Sun*, which do enter it, and render it lucid, the rest of the *Sun's* Beams being intercepted by the opake Body of the *Earth*; and the Parts of this *Penumbra* will have different Degrees of Illumination, according as they are nearer or further removed from the Shadow. The Space of the *Penumbra* is to be determined in this Manner:

Plate VIII.  
Fig. 1.

LET the Circle A E F G represent the *Sun*, H E D any opake Sphere, for Example, the *Moon*, it being her *Penumbra* that we are at present concerned with; S C the Line which joins the Centers of both Spheres. Draw the Line F D O, touching the left Side of the *Sun*, and the right Side of the *Moon*; and the Line A H P, which touches the right Side of the *Sun*, and the Left of the *Moon*; Let these two Lines cut the Line S C in I. The Point I remaining immoveable, either of the right Lines I D O, or I H P, being extended indefinitely, let them be turned round the *Axis* I M, with a conical Motion, so that they may always touch the  
Globe











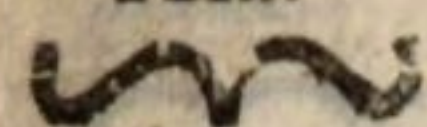
Globe of the *Moon*; there will by that means be generated an indefinite conical surface, including both the Shadow and the circumambient Space ODM PHM; into which Space some Rays of the *Sun* are hindered from entering by the opaque Body of the *Moon*: And this is the Space which we call the *Penumbra*, which is darker in X or Y, which are nearer the Borders of the Shadows, than in V and N, which are nearer the conical Surface. For the Places X and Y are illustrated with a smaller Portion of the *Sun's* Disk, than the other Places further distant from the *Axis* of the Cone. Now, if the *Earth* come within this Space, a certain Portion of its Surface at S may be included in the total Darkness, and the Inhabitants of that Region will see a total Eclipse of the *Sun*; but those who live without this Shadow, but are still within the *Penumbral* Space, as about Q and X, will have no total Darkness, some Part of the *Sun's* Disk being still visible, while the rest is hid by the *Moon*. For let us draw from Q the Line QD, touching the Globe of the *Moon*; which being produced to the *Sun*, the Point Q being immoveable, if the Line QD indefinitely extended be moved by a conical Motion round the *Moon*, the conical Surface it describes, will cut off a Portion of the *Sun's* Disk, which is covered by the *Moon*.

WE find the Dimensions of the Cone of the *Penumbra* in this Manner: Let the Circle HDL represent the opaque Sphere of the *Moon*, SC the Line joining its Center with the Center of the *Sun*; and let CB, the Semidiameter of the *Moon*, be perpendicular to CS, and BF parallel to it touching the *Moon* in B. Make the Angle BCD equal to the apparent Semidiameter of the *Sun*, and through D draw DG a Tangent to the *Moon*. And by the *Lemma* premised, the Angle FEG will be equal to the Angle BCD, or to the apparent Semidiameter of the *Sun*; and therefore,

Plate VIII.  
Fig. 2.  
The Dimensions of the  
conical Penumbra.



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fore, since the Line  $EF$  goes to the Center of the *Sun*, the Line  $EDG$  must touch the inferior Limb of the *Sun*: But it also touches the *Moon*; and therefore the Point  $I$  of this Line being immoveable, if it be carried by a conical Motion round the *Moon*, it will generate the Surface which includes the *Penumbra*. And because of the Parallels  $EF$ ,  $CS$ , the alternate Angles  $FEI$  and  $EIC$  will be equal; but the Angle  $EIC$  is the Semiangle of the Cone, and  $FEI$  is the apparent Semidiameter of the *Sun*; and therefore half the Angle of the *Penumbral* Cone is always equal to the apparent Semidiameter of the *Sun*. The Cone therefore of the total Shadow, and that Part of the *Penumbral* Cone which lies between the *Sun* and the *Moon*, are equal and similar Figures; for they have their vertical Angles and Bases equal.

Plate VIII.  
Fig. 3.

The Height  
of the  
Earth's  
Shadow.

The Height  
of the  
Moon's  
Shadow.

THE Height of the Shadow of the *Earth* is thus determined: Let  $CT$  be the Semidiameter of the *Earth*,  $TM$  the Height of the Cone or Shadow: If  $TM$  be the Radius,  $CT$  will be the Sine of the Angle  $TM C$ , which is half the Angle of the Cone. And this Angle is equal to the apparent Semidiameter of the *Sun*, as has been shewed, and in the mean Distance of the *Sun*, is about 16 Minutes. Let therefore the Sine of 16 Minutes be to the Radius, as the Semidiameter of the *Earth* to a fourth; and we shall find  $TM$  equal to 214, 8 Semidiameters of the *Earth*: But when the *Sun* is at his greatest Distance, half the Angle of the Cone is 15 Minutes, and 50 Seconds; and the Height of the Shadow becomes 217 Semidiameters of the *Earth*: And since the Diameter of the *Earth* is to the Diameter of the *Moon*, as 100 is to 28; the Altitude of the *Earth's* Shadow will be to the Altitude of the *Moon's* in the same Proportion; for the conical Shadows are similar Figures; and therefore the Height of the *Moon's* Shadow will be 59,36 Semidiameters of the *Earth*. Hence, if the Distance  
of



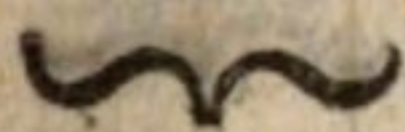
of the *Moon* from the *Earth* be greater than her mean Distance, which is about 60 Semidiameters of the *Earth*, the Shadow of the *Moon* cannot reach the *Earth*; in which Case there may be a central Eclipse of the *Sun*, but not a total one: But round the *Moon*, there will appear Part of the *Sun's* Body, in the Form of a luminous Circle, which, like a bright shining Ring of Gold, will embrace the Body of the *Moon*. It also follows, that if in the Time of the Eclipse, the Anomaly of the *Moon* be less than three Signs, or bigger than nine Signs, there can no-where be a total Eclipse of the *Sun*; for in all these Degrees of Anomaly, the Distance of the *Moon* is greater than her mean Distance.

To find how much of the *Earth's* Surface can be involved in the *Moon's* Shadow in the Time of an Eclipse, when it directly falls upon it: Let us suppose the Distance of the *Sun* to be the greatest that can be, in which Case the Height of the conical Shadow of the *Moon* is about 60 Semidiameters of the *Earth*: Let us likewise suppose the Distance of the *Moon* from us, to be the least that can be, that the *Earth* may receive the most of the Shadow. This least Distance of the *Moon* from the *Earth* is about 56 Semidiameters of the *Earth*: Now let *L* represent the *Moon*, and *T* the Center of the *Earth*; *LT* the Distance of the *Moon* from the *Earth*, which is equal to 56 Semidiameters; and since *LM* is 60, *TM* must be four Semidiameters, and *TB* will be to *TM* as 1 to 4. But as *TB* is to *TM*, so is the Sine of the Angle *TMB*, which is  $15^{\circ} 50''$ , to the Sine of the Angle *TBM*; by which Means we find the Angle *TBM* to be 63 Minutes and 10 Seconds. But the Angle *ATB* is equal to both *TMB* and *TBM*, by 32 *Prop.* Book 1st. of *Euclid*; and therefore the Angle *ATB* is 79 Minutes, and such is the Arch *AB*; the double of which is the Arch *BC*, equal to 158 Minutes, or

*The Portion  
of the Earth's  
Surface that  
may be in-  
volved in  
the Shadow.*

Plate VIII.  
Fig. 4.



Lecture  
XII

or to 180 *English* Miles. We have here supposed the *Axis* of the Shade to pass thro' the Center of the *Earth*; which it does when the Centers of the *Sun*, *Earth*, and *Moon*, are in the same Right Line precisely: But when the three Centers do not lie in the same Right Line, the conical Shade is cut obliquely, and the Figure of it upon the *Earth* is Oval, whose Diameter is easily to be determined by the Distance of the *Moon* from the *Sun* seen from the Center of the *Earth*.

How much of  
the Surface  
may be in-  
cluded in the  
Penumbra.  
Plate VIII.  
Fig. 5.

IF we inquire how much of the Surface of the *Earth* can be involved in the *Penumbra*, it may be found by this Means: Let us suppose the Apparent Diameter of the *Sun* to be the greatest, which is when the *Earth* is in her *Perihelion*, and is about  $16' 23''$ . Let *ABD* be the *Earth*, *L* the *Moon*, and *AMB* be half the Angle of the Cone, which is likewise  $16' 23''$ : By which we shall find the Height of it *LM*, equal to 58 and a half Semidiameters of the *Earth*. Let the *Moon* be in her *Apogee*, and therefore at her greatest Distance from the *Earth*, which is 64 Semidiameters of the *Earth*; and *TM* is equal to both *TL* and *LM*, that is to  $122\frac{1}{2}$  Semidiameters. But by a Trigonometrical Theorem, *TB* is to *TM*, as the Sine of the Angle *TMB* is to the Sine of the Angle *MBN* or *MBT*. But *TB* is to *TM* as 1 is to  $122\frac{1}{2}$ , and the Angle *TMB* is 16 Minutes 23 Seconds; and therefore we shall find out the Angle *MBN* to be 35 Degrees and 42 Minutes, which Angle is equal to both the Angles *TMB* and *MTB*. If therefore from the Angle *MBN* 35 Degrees 42 Minutes, we subtract the Angle *TMB*, there will remain the Angle *MTB* 35 Degrees 25 Minutes, which is the Measure of the Arch *AB*; whose double 70 Degrees and 50 Minutes, is equal to the Arch *CAB*, which makes about 4900 *English* Miles.

IF the conical Shadow of the *Earth* at the Distance of the *Moon*, be cut with a Plane perpen-



perpendicular to its *Axis*, the Section will be a Circle, which is called the Shadow, whose Apparent Diameter seen from the Center of the *Earth* is thus determined: Let  $T$  be the Center of the *Earth*,  $CMT$  half the Angle of the Cone,  $FLH$  the Section whose Diameter is  $FH$ . Having the Angle of the Cone, we by that Means can find its Altitude  $TM$ ; but we have also  $TL$ , the Distance of the *Moon* from the *Earth*; and therefore we can find  $ML$ : But we have also the Angle  $FML$ ; therefore we can find out  $FG$  half the Diameter of the Shadow at the Distance of the *Moon*: And therefore in the rectangled Triangle  $FTG$ , having the two Sides  $FG$  and  $TG$ , we can find by Trigonometry the Angle  $FTG$ , the apparent Semidiameter of the Shadow seen from the Center of the *Earth*. It may likewise be thus found: Having  $FT$  the Distance of the *Moon* from the *Earth*, and  $CT$  the Semidiameter of the *Earth*; in the Triangle  $CF T$ , we may find out the Angle  $CF T$ , which is equal to the two Angles  $FMT$  and  $FTM$ : If therefore we subtract the Angle  $FMT$ , which is half the Angle of the Cone, from the Angle  $CF T$ , we shall find the Angle  $FTM$  or  $FTL$ : The Angle  $CF T$  is the apparent Semidiameter of the *Earth*, seen from the *Moon*, and is called the *Horizontal Parallax* of the *Moon*, the Reason of which we shall shew, when we come to treat about *Parallaxes*. These apparent Semidiameters of the *Earth*, or *Horizontal Parallaxes* of the *Moon*, constantly vary as the Distance of the *Moon* does, and they are found ready calculated in all *Astronomical Tables*.

The Apparent Diameter of the Shadow of the *Earth* at the Distance of the *Moon* determined.  
Plate VIII.  
Fig. 3.

Another way of finding the same.

The Horizontal Parallax of the *Moon*.

LET  $\Omega M$  be a Portion of a Line in the Plane of the *Ecliptick*,  $\Omega L$  a Portion of the Lunar Orbit which the *Moon* moves through, about the Time of *Full Moon*; which because it is small, may be represented by a Right Line. Let the Circle  $FMO$  represent the Shadow of the *Earth* at the Distance of the *Moon*, and its Center  $G$ ;  $GL$  is the Latitude of the *Moon* in the Time

Plate VIII.  
Fig. 6.



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Plate IX.  
Fig. 1, 2.

The Limits  
of Eclipses.

Plate IX.  
Fig. 3.

The Limits  
determined.

Time of *Full Moon*, which is almost equal to the shortest Distance of the *Moon* from the Plane of the Ecliptick. It is manifest that if  $GL$ , the Latitude of the *Moon*, be greater than the Sum of the Semidiameters of the *Moon* and Shadow; then the *Moon* will no Part of it enter into the Shadow: But if the Latitude of the *Moon* be just equal to these two Semidiameters, then the Limb of the *Moon* will just touch the Shadow, but not enter it: But if the Latitude of the *Moon* be less than this Sum, but greater than their Difference, there will be a partial Eclipse; and if the Latitude of the *Moon* be less than the Difference of the Semidiameters of the *Moon* and Shadow, the Eclipse will be total: And by this means we can find out the Ecliptick Terms or *Limits*, which are such, that if the Distances of the *Moon* from the *Node* be less than they are, in the Time of *Full Moon*, there will be an Eclipse; if greater, there can be no Eclipse. Let  $\Omega S$  represent a Portion of a Line in the Plane of the Ecliptick, parallel to the *Earth's* Orbit;  $\Omega L$ , a Portion of the *Moon's* Orbit;  $SL$ , the Latitude of the *Moon*, when at *Full*: And let us suppose the Latitude to be such, that the Margin of the *Moon* may just touch the Shadow, and let the *Node* be at  $\Omega$ . The Angle  $L \Omega S$  is the Inclination of the Orbit of the *Moon* to the Plane of the Ecliptick, which is five Degrees; and  $LS$  the Latitude of the *Moon*, when its Limb touches the Shadow, equal to 66 Minutes; and therefore in the rectangular Triangle  $\Omega LS$ , having  $LS$  and the Angle  $L \Omega S$ , we can find  $\Omega S$ , the Distance of the *Node* from the Point of the Ecliptick opposite to the *Sun*, which is 754 Minutes, or 12 Degrees 34 Minutes. And if in the Time of *Full Moon*, the *Moon's* Place in the Ecliptick be further distant from the *Node*, than 12 Degrees 34 Minutes, there can then be no Eclipse of the *Moon*.

LET  $L$  be the Center of the *Moon*, whose conical Shadow is  $DME$ . Imagine this Shadow cut

at

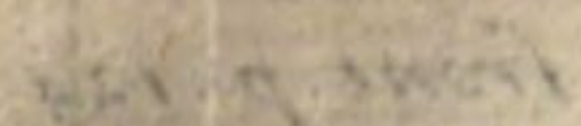




9.5.  
N

M



[illegible]



at the Distance of the *Earth*, with a Plane perpendicular to its *Axis*; the Section will be a Circle, whose Semidiameter  $TP$  is called the Semidiameter of the *Moon's* Shade: Now the Angle under which this Semidiameter appears, seen out of the *Moon*, is equal to the Difference of the Semidiameters of the *Sun* and *Moon* seen from the *Earth*: For the Angle  $LPD$  is the apparent Semidiameter of the *Moon* seen from the *Earth*, which is equal to the two internal Angles  $PML$  and  $PLM$ ; and therefore, if we subtract from the Angle  $LPD$ , which is the apparent Semidiameter of the *Moon*, the Angle  $PML$ , which is equal to the apparent Semidiameter of the *Sun*, there will remain the Angle  $PLT$ , the apparent Semidiameter of the Shadow seen from the *Moon*.

Lecture XII.

Plate IX.  
Fig. 4.

The Diameter of the Moon's Shadow at the Earth, when seen from the Moon.

AGAIN: Let  $L$  be the Center of the *Moon*,  $AMB$  the *Penumbral* Cone of the *Moon*, extended as far as the *Earth*, and its *Axis*  $MT$ ; if this Cone at the Distance of the *Earth* be cut by a Plane transversely, the Section will be a Circle whose Semidiameter is  $AT$ , and is called the Semidiameter of the *Penumbra*. And the Angle under which it appears from the *Moon*, is the Angle  $TLA$ , which is the external Angle of the Triangle  $LMA$ , and is equal to both the inward Angles  $LAM$  and  $LMA$ . But the Angle  $LMA$  is half the Angle of the Cone, which is the same with the apparent Semidiameter of the *Sun*; and  $MAL$  or  $CAL$  is equal to the apparent Semidiameter of the *Moon* seen from the *Earth*; and therefore the Apparent Semidiameter of the *Penumbra* seen from the *Moon*, is equal to the Sum of the Semidiameters of both the *Sun* and *Moon*.

Plate IX.  
Fig. 5.

The Apparent Semidiameter of the Penumbra.

IF the *Sun* had no apparent Motion arising from the real Motion of the *Earth*, the Way of the *Moon* from the *Sun* would be the same with her real Way in her Orbit: But because, while the *Moon* is proceeding in her Orbit, the *Sun* also seems to move in the *Ecliptick*, the Way the *Moon* moves towards

The Way of the Moon from the Sun.



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XII.

Plate IX.  
Fig. 6.

towards or from the *Sun*, will be different from that which she has in her Orbit; and its Inclination to the Ecliptick will be greater, than the Inclination of the Orbit to it. Let  $\Omega A$  be a Portion of the *Moon's* Orbit produced to the Ecliptick: And suppose the *Sun* and *Moon* in Conjunction in the *Node*: Now, then, while the *Moon* in her Orbit describes the Space  $\Omega L$ , the *Sun* by his apparent Motion will describe the Space  $\Omega S$  in the Ecliptick, and  $SL$  will be the Way of the *Moon* from the *Sun*. Now if two Bodies be both moved the same Way, but one faster than the other, their relative Motion, whereby the one recedes from the other, is the same as if the slowest Body stood still, and the other moved on with the Difference of Velocities, as we have demonstrated in our Physical Lectures. Thro' the Place of the *Moon*  $L$ , draw  $BL$  parallel to the Ecliptick, to which let  $\Omega B$  be perpendicular. Now while the *Moon* in her Orbit describes the Space  $\Omega L$ , its Motion according to the Ecliptick is equal to the Space  $BL$ ; take  $Ll$  equal to  $\Omega S$ , and draw  $\Omega l$ , it will be parallel to  $SL$ ; and the Motion of the *Moon* from the *Sun* will be the same as if the *Sun* had remained in the *Node*, and the *Moon*, according to the Ecliptick, had been carried with the Velocity  $Bl$ , which is the Difference of the Velocities of the *Sun* and *Moon*, according to the Ecliptick. Because the Angles  $BL\Omega$  and  $Bl\Omega$  are but small, the Angle  $BL\Omega$  will be to the Angle  $Bl\Omega$ , as  $Bl$  is to  $BL$ ; that is, as the Difference of the Motions of the *Sun* and *Moon*, according to the Ecliptick, is to the Motion of the *Moon*, in the Ecliptick, so will the Angle which the Orbit of the *Moon* makes with the Ecliptick, be to the Angle  $Bl\Omega$ , which is equal to the Angle  $LSE$ , or the Inclination of the Way of the *Moon* from the *Sun* to the Ecliptick: And by this means we can find out the Angle which a Circle of Latitude, drawn through any Point of the Ecliptick,











tick, makes with the Way of the *Moon* from the *Sun*. For in the rectangular spherical Triangle, which the Ecliptick, the Circle of Latitude, and the Way of the *Moon* from the *Sun* do form, we have one Angle, which is the Inclination of the Way of the *Moon* from the *Sun* to the Ecliptick, and its Base, which is the Distance of the Circle-Latitude from the *Node*; and therefore we can find the other acute Angle.



## LECTURE XIII.

*Of the Projection of the Moon's Shadow  
on the Disk of the Earth.*



IF a Right Line be projected on a Plane that is parallel to it, by letting fall from all its Points Perpendiculars on the Plane, the Projection, or the Place where all Perpendiculars meet with the Plane, will be a Right Line, parallel and equal to the former Line which was projected. For the Perpendiculars that fall from the Extremities of the Right Line, are parallel and equal; and therefore the Lines which join them will be parallel and equal.

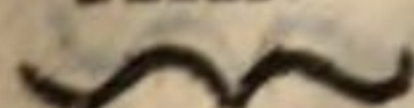
HENCE, if two Right Lines touching one another, be parallel to any Plane, the Projections of these two Lines upon that Plane, will contain an Angle, equal to the Angle the Lines themselves make together; this is plain by *Prop. 10. Book XI. of Euclid*. Hence all Plane Figures projected on a Plane parallel to themselves have  
for



Lecture  
XIII.

Plate X.  
Fig. 1.

for their Projections, Figures exactly similar and equal to themselves.



BUT if a Line be inclined to any Plane, its Projection upon that Plane, made by letting fall from it Perpendiculars to the Plane, will be to the Line itself, as the Cosine of the Inclination of the Line is to the Radius. For let  $AB$  be a Line inclined to the Plane, and let  $DE$  represent the Plane: Letting fall from the Points  $A$  and  $B$ , the Perpendiculars  $Aa$ ,  $Bb$ ;  $ab$  will be the Projection of the Line  $AB$ ; to which if we draw through  $B$  the parallel Line  $BC$ , meeting with the Perpendicular  $Aa$  in  $C$ , this Line  $BC$  is equal to  $ab$ : But  $BC$  is to  $AB$ , as the Sine of the Angle  $CAB$ , or the Cosine of the Angle  $ABC$  to the Radius; that is, as the Cosine of the Angle of Inclination is to the Radius, so is  $ab$  to  $AB$ . Hence it follows, that every Figure, whose Plane is perpendicular to the Plane of the Projection, is projected in a right Line. For the Perpendiculars from every Point of the Figure, will all fall upon the common Intersection of the Plane of the Figure, with the Plane of the Projection. Such a Projection of Lines and Figures is called an *Orthographical Projection*.

An Ortho-  
graphical  
Projection  
what?

If we imagine a Plane to pass through the Center of the *Earth*, so that the Line which joins the Centers of the *Sun* and *Earth*, may be perpendicular to this Plane, it will make on the Surface of the *Earth* a Circle, which will separate the illuminated Hemisphere of the *Earth* from the dark. This Circle we before called the Circle bounding Light and Darkness, but we will now call it the illuminated Disk; which Disk is directly seen by a Spectator placed at the Distance of the *Moon*, in the Right Line which joins the Centers of the *Sun* and *Earth*. Upon this Circle the *Earth's* Equator, its Parallels, Poles, and all the other Circles which we imagined, are to be supposed, projected *Orthographically*. For all Lines drawn from the Center

The Disk of  
the Earth.

The Ortho-  
graphical  
Projection  
on the Disk.



Center of the *Sun* to every single Point of the Disk, are to be accounted parallel; and therefore since that Line which is drawn to the Center of the Disk is perpendicular to it, all the rest will be perpendicular to it; and therefore all Lines drawn from the Center of the *Sun*, and passing through every Point of any Circle upon the *Earth's* Surface, when they are produced, will be perpendicular to the Plane of the Disk. Moreover a Spectator in the *Moon* will see all Countries, Cities and Towns, to move upon the Disk, which Motion is occasioned by the Rotation of the *Earth* round its *Axis*, and every Point will have its Way on the Disk; for by the diurnal Gyration all Places describe either the *Æquator*, or one of its Parallels; and if the *Sun* be in the Plane of the *Æquinoctial*, or rather, if the Plane of the *Æquinoctial* passes through the *Sun*, the *Æquinoctial* and all its Parallels are in that Case projected into right Lines; for they will all be perpendicular to the Disk, or the Plane of the Projection. But in other Positions the Projections of these Circles will be Ellipses, which are the Ways that all the Places of the *Earth* are seen to move in on the Disk: Now if through the *Pole* and the *Sun* there be a great Circle drawn which cuts the *Earth*, and this Circle be projected on the Disk, we shall have an universal Meridian, The universal Meridian. to which when any Place is observed to come, the Inhabitants of that Place will have Mid-day. And when any Place is first seen to touch the *Western* Limb, or Edge of the Disk, the Inhabitants of that Place will then see the *Sun* arising upon them. But a Spectator at the *Moon* will see the Place to rise and come upon the Disk, and will see it move towards the *East*: And as soon as it has passed the universal Meridian, the Place then being gone to the *Eastward*, the *Sun* seen out of the *Earth* from the Place will appear to move *Westward*. But when the Place comes to the *Eastern* Edge of the



Lecture XIII. the Disk, our Spectator in the *Moon* will observe the Place to set in the Disk, and hide itself in the dark Side; but the Inhabitants of that Place upon the *Earth's* Surface will see the *Sun* set in the *West*, and withdraw himself out of Sight.

*The Bigness of the Disk determined.*

*The Projection of the Moon's Way on the Disk.*

THE Bigness of the Disk is to be estimated by the Angle under which the *Earth* is seen from the *Moon*, and is of the same Quantity with the *Horizontal Parallax* of the *Moon*. And if from the *Moon* there be let fall a Perpendicular upon the Plane of the Ecliptick, which measures the Distance of the *Moon* from the Ecliptick, this Line being parallel to the Plane of the Disk, will be projected into a Line equal and parallel to itself; and the Angle under which the Projection of this Line appears from the *Moon*, will be equal to the Angle under which the same Line is seen from the *Earth*; for equal right Lines at equal Distances, being seen directly, appear under equal Angles. The Way of the *Moon* from the *Sun*, if such a small Portion of it be taken as is turned towards the Disk in the Time of an Eclipse, may be esteemed as a Right Line, and will be projected upon the Disk into a Right Line, which is equal to itself; and its Projection with the Projection of the Circle of Latitude will contain the same Angle, that these two Lines make in the Heavens: The Spectator in the *Moon* will see this Line to be described upon the Plane of the Disk, by the Center of the Shadow and of the *Penumbra* which coincide.

Plate X.

Fig. 2, 3, 4, 5.

LET now the Circle D G K represent the Disk of the *Earth*, whose Semidiameter let us suppose to be divided into as many Parts as the *Horizontal Parallax* of the *Moon* contains Minutes and Seconds. Let the Line N T represent the Distance of the *Moon* from the Ecliptick in the Time of *New Moon*, projected on the Plane of the Disk; which also must consist of as many Parts as the Latitude of the *Moon* contains



contains Minutes; and let likewise  $K \Omega$  be a Portion of the Ecliptick,  $\Omega l$  a Portion of the Way of the *Moon* from the *Sun*, both projected on the Plane of the Disk. From the Center  $T$ , let fall on the Way of the Shadow a Perpendicular  $TV$ ; this Line will measure the least Distance that is between the Centers of the Disk and Shadow. At the Center  $V$  describe a small Circle, whose Semidiameter may be equal to the Difference of the apparent Semidiameters of the *Moon* and *Sun*; this Circle will represent the Breadth of the Shadow: For we have shewed, that this Shadow seen from the *Moon*, at the Distance of the *Earth*, was equal to the Excess whereby the apparent Diameter of the *Moon* exceeds that of the *Sun*. Again, let there be described another Circle  $HM$ , at the Center  $V$ , whose Semidiameter  $VH$  bears the same Proportion to the Semidiameter of the Disk, as the Sum of the Semidiameters of both *Sun* and *Moon* bears to the apparent Semidiameter of the *Earth* seen from the *Moon*; or, which is the same, to the *Horizontal Parallax* of the *Moon*: This Circle will represent the *Penumbra*, projected at its shortest Distance from the Center of the Disk: For we have shewed, that the apparent Semidiameter of the *Penumbra*, seen from the *Moon*, was equal to the Semidiameters of both *Sun* and *Moon*. And therefore, if this Circle does not touch the Disk, there can be no *Eclipse*; that is, if the Distance  $VT$  be greater than the Sum of the Semidiameters of the Disk and the *Penumbra*; or, which is the same, greater than the Sum of the Semidiameters of the *Sun* and *Moon*, and of the *Horizontal Parallax* of the *Moon*, there can be no *Eclipse*: But if the Distance  $VT$  be equal to this Sum, the *Penumbra* will touch the Disk, without obscuring the *Sun*, or any Part thereof: But if  $VT$  be less than this Sum, that is, if it be less than  $VM$  and  $TR$ , the *Penumbra* will cover some Part of the Disk; and those that lie within the Segment  $RZMY$ , will see at least a partial *Eclipse* of the *Sun*. But if the Distance  $VT$  be less than

Lecture  
XIII.The Proportion of the  
Moon's Latitude.

The Shadow projected.

The Penumbra projected.

When there can be no  
Eclipse of the Earth.When there must be an  
Eclipse.



Lecture  
XIII.

*Total Eclipses of the Sun.*

the Difference of the Semidiameter of the Disk, and the Semidiameter of the Shadow, then the Shadow will cover some Part of the Disk, and make a total *Eclipse* of the *Sun* in all those Places it passes over. These total *Eclipses* are always but for a small Portion of Time, because the Diameter of the total Shade is but small; the apparent Diameter of the *Moon* never exceeding the apparent Diameter of the *Sun*, but by a very small Matter, which is seldom equal to two Minutes; which Space the Center of the Shade passes over on the Disk in the Space of four Minutes of Time: But yet the Stay that it may make on any Place, may be longer than this; upon the Account of the Motion of the Place which follows the Shade.

*The Ecliptick Limits.*

HENCE we may know the *Ecliptick Limits*, or the Distance of the *Moon* from the *Nodes*, at the Time of *New Moon*; so that an Eclipse of the *Sun* may be possible: For let the Circle R O G represent the Disk of the *Earth*;  $\Omega$  T K and  $\Omega$  N, the Projections of a Portion of the Ecliptick, and of the Way of the *Moon* from the *Sun* upon the Plane of the Disk. And let T V be the least Distance of the Center of the Disk and Shadow; which suppose equal to the Sum of the Semidiameters of the Disk and *Penumbra*: Then in the rectangular Triangle  $\Omega$  T V, we have the Side T V; which, when it is biggest, is about  $94\frac{1}{2}$  Minutes. We have likewise the Angle at  $\Omega$ , which, when it is least, is 5 Degrees and 30 Minutes: From whence we shall find  $\Omega$  T equal to 986 Minutes; or to 16 Degrees and 26 Minutes. And since in this Case the *Penumbra* only touches the Disk, it is plain, that there can be no Eclipse, unless the *New Moon* be nearer to the *Node*, than 16 Degrees and 26 Minutes.

Plate X.  
Fig. 6.

LET the Circle R K G, as before, represent the Disk of the *Earth*;  $\Omega$  T K a Portion of the Ecliptick projected on the Plane of the Disk;  $\Omega$  / the Way of the *Moon's* Shadow on the Disk; T N the Latitude of the *Moon*, and T V the shortest Distance of the Centers of the Shadow and Disk.

Let



Let the Circle  $OPQ$  be the *Penumbra*, moving from  $D$  by  $V$  to  $I$ ; in the Middle of which is a small Circle representing the Shadow: And let us suppose we know the Time of the Conjunction; that is, when the Center of the Shadow is in  $N$ , which we find by Astronomical Tables; by that Means we can find the Time when the Center of the Shade is in  $V$ , that is, the Time of the Middle of the general Eclipse. For in the rectangled Triangle  $T V N$ , we have  $T N$  the Latitude of the *Moon*, and the Angle  $T N V$ , which the Circle of Latitude makes with the Way of the *Moon* from the *Sun*; and therefore we can find  $V N$  and  $T V$ . But by the horary Motion of the *Moon* from the *Sun*, we can find out the Time the Shadow will pass through the Space  $N V$ ; and this Time, either added or subtracted from the Time of the Conjunction, will give the Time of the Middle of the Eclipse. Moreover, in the Triangle  $D V T$ , right-angled at  $V$ , we have the Side  $D T$ , which is the Sum of the Semidiameters of the *Disk* and *Penumbra*, and the Side  $T V$  the shortest Distance of the Shade from the Center of the *Disk*; therefore we can find out the Side  $D V$ , and by it the Time when the Shade enters the *Disk*; and from that we shall have the Semiduration, or half the Time the Eclipse continues upon the *Disk*. After the same Manner we shall find the Time when the Shade leaves the *Disk*, or the Time of the End of the Eclipse.

HAVING the Place of the *Sun* in the Ecliptick for any Moment of Time, we can thereby find the Place on the Surface of the *Earth*, upon which the *Sun* at that Time is vertical: For the Latitude of the Place is equal to the Declination of the *Sun* at that Time; and its Longitude is found by turning the Time from the Meridian into Degrees and Minutes of the *Æquator*, allowing for every Hour 15 Degrees, and for every Minute of an Hour 15 Minutes of a Degree. For Example, The Longitude of a Place, in whose *Vertex* the *Sun* is, when at *Oxford* we reckon nine and an

*The Time of  
the Middle  
of the  
Eclipse.*

*The Semidu-  
ration.*

*To find the  
Place to  
which the  
Sun is ver-  
tical.*



Lecture  
XIII.

half in the Morning, is known by subtracting 9 and a half from 12, and then there will remain 2 Hours and thirty Minutes; which, multiplied by 15, make 37 Degrees and 30 Minutes. And therefore that Place will be 37 Degrees and 30 Minutes to the East of Oxford

Plate X.  
Fig. 7.

The Eleva-  
tion of the  
Earth's Pole  
above the  
Disk.

To find the  
Position of  
the Meri-  
dian, which  
passes thro'  
the Sun.

LET the Circle F R K represent the Disk, as before; F T K a Portion of the Ecliptick projected on the Disk; on which from the Center erect the Perpendicular T R: This Line will be the Projection of the *Axis* of the Ecliptick, and the Point R of its Pole. Let the Point P be the Projection of the *Pole* of the *Earth*: Through T and the Pole P let us imagine a Circle to pass, and to be projected on the Disk. This Circle will represent the universal Meridian; and the Elevation of the Pole above the Plane of the Disk, will always be equal to the Declination of the *Sun*. For the Arch of the Meridian between the *Sun* and the *Periphery* of the Disk, is a Quadrant of a Circle; and the Arch of the Meridian between the *Æquator* and the Pole, is likewise a Quadrant: Wherefore taking away from equal Arches the common Arch T P, there will remain P S, the Elevation of the Pole above the Disk, equal to the Distance of the *Sun* from the *Æquator*.

It is here to be observed, that when the *Sun* is in the Signs ♈ ♉ ♊ ♋ ♌ ♍, or rather when the *Earth* is in the opposite Signs, the Point S, wherein the universal Meridian cuts the Limb of the Disk, will fall towards the right Hand of the Pole of the Ecliptick. But when the *Sun* is in the other six Signs, the Point S falls upon the other Side of the Pole of the Ecliptick, contrary to what happens when the Projection is supposed to be made in a Plane parallel to the Disk at the Orbit of the *Moon*.

To find the Angle R T S, or the Arch of the Disk intercepted between the Pole of the Ecliptick and the Point S: In the right-angled spherical Triangle R P S, we have the Arch R P, the Distance of the Poles of the Ecliptick and *Æquator*  $23\frac{1}{2}$  Degrees;



grees; also the Side  $PS$ , which is equal to the Declination of the *Sun*: Wherefore, by *Trigonometry*, we may find the Side  $RS$ , or the Measure of the Angle  $RTS$ . Lecture XIII.

To find the Place upon the *Earth's* Surface *To find the Place of the Earth,*  
 $Q$ , where the *Sun* rising begins to be in an Eclipse *which is first touched by the Penumbra,*  
 in its upper Limb, and where the Shadow enters the Disk: Draw through the Pole the Meridian  $PQ$ , to the Point  $Q$ , where the *Penumbra* first touches the Disk. And first, in the right-lined Triangle  $DTV$ , having  $DT$  and  $TV$ , we may know the Angle  $DTV$ ; to which if we add or subtract a given Angle  $VTP$ , which is the Sum or Difference of two known Angles  $VTN$  and  $NTB$ , we shall have the Angle  $QTP$ . And then in the spherical Triangle on the Surface of the *Earth*  $SPQ$ , which is right-angled at  $S$ , we have  $SP$  equal to the Declination of the *Sun*; and the Arch  $SQ$ , which is the Measure of the known Angle  $STQ$ ; from whence we may find the Arch  $PQ$ , the Complement of the Latitude of the Place  $Q$ , and the Angle  $SPQ$ , whose Complement to two Rights is the Angle  $QPT$ , contained between the Meridian of the Place  $Q$ , and the Meridian of that Place to which the *Sun* is then vertical; and is the Measure of the Distance of the Meridian of the Place  $Q$ , from that of the Place which has the *Sun* in the Meridian at that Time. But we know the Place which has the *Sun* at that Time in its Meridian; wherefore we know likewise the Meridian or Longitude of the Place  $Q$ : But its Co-Latitude  $PQ$  was before found out. Having therefore both the Longitude and Latitude of that Place, the Place itself must be known.

By the same Method we can find out the Place of the *Earth*, which is first involved in the total Shadow. And by a like Process we may find out the Place  $M$  on the Surface of the *Earth*, which is under the total Shadow at any Point of Time, either before or after the Middle of the Eclipse. For the Time being known, we may find by the horary Motion of the *Moon* from the *Sun*, the



Lecture  
XIII.



*The Determination of the Place involved by the Shadow, for any given Time.*

Line  $MV$  and the Point  $M$ , where the Center of the Shadow lies; and in the right-lined Triangle  $MVT$ , having  $MV$  and  $VT$ , we may find  $MT$  and the Angle  $MTV$ ; to which if you add or subtract the known Angle  $FTP$ , we shall have the Angle  $MTP$ . But  $MT$  is the Sine of an Arch of the vertical Circle which passes through  $M$ , and the Point of the *Earth's* Surface directly under the *Sun*, the Semidiameter of the Disk being made the Radius. And therefore, if we say, As the Semidiameter of the Disk is to  $MT$ , so is the Radius to the Sine of an Arch; the Arch found out by this Proportion will be the Distance of the *Sun* from the *Vertex*  $M$ : And therefore in the spherical Triangle on the Surface of the *Earth*  $MPT$ , we have  $PT$  the Distance of the *Sun* from the Pole; and  $MT$  the Distance of the *Sun* from the *Vertex*, and the Angle  $MTP$ . Hence we can find  $MP$ , which is the Complement of the Latitude of the Place; and the Angle  $MPT$ , which shews the Difference of the Meridians of the Place  $M$ , and of that Place to which the *Sun* at that Time is vertical; which Place by the Time is known, and therefore we can find the Place  $M$ . And by this Method we may find several Places over which the Shade does pass; and if they be joined by Lines, we shall have the Way of the Shade upon the Surface of the *Earth*.

Plate X.  
Fig. 8.

*The Portion of the solar Disk obscured by the Eclipse.*

THE Portion of the Diameter of the *Sun* obscured by the *Moon*, is known by the Situation of the *Spectator* within the *Penumbra*; or by his Distance from the Center of the Shade. For let  $ASB$  be the Diameter of the *Sun*, parallel to the Diameter of the *Penumbra*  $EF$ ; draw the Line  $MCB$ , touching the superior Edges of both *Sun* and *Moon*; and let  $FCA$  also touch the inferior Margin of the *Sun*: Then the Angle  $ACB$  is equal to the apparent Diameter of the *Sun*; and the Triangles  $ACB$  and  $MCF$  are similar. Suppose then a *Spectator* within the *Penumbra* at  $G$ ; draw the Line  $GCP$ , touching the Globe of the *Moon*, which nearly passes through the former





mer Point C, and cuts off AP, that Part of the *Sun's* Diameter, which is obscured by the *Moon*, to the *Spectator* in G. But the Right Line GP, since it very nearly passes thro' the *Vertex* of the Triangles MCF and ACB, will divide the Bases AB and MF in a like Proportion. And therefore AP is to AB, as FG to MF; that is, the obscured Portion of the *Sun's* Diameter is to the whole Diameter, as the Distance of the Place from the Edge of the *Penumbra*, which is FG, is to FM the Semidiameter of the *Penumbra* diminished by the Semidiameter of the total Shadow.

THE *Astronomers* commonly divide the Diameters of both Solar and Lunar Disks into twelve equal Parts, which they call *Digits*; and by them they measure the Quantity of the Obscuration. And they say, the Eclipse is of so many *Digits*, as the obscured Portions consists of such Parts.

IF we know the Position of any Place upon the Disk for any Point of Time, and it be desired to find the *Phasis* of the Eclipse for that Time, as it is seen from the Place; it is to be found in this Manner: Let S be the Position of the Place on the Disk; find out for that Point of Time, the Place of the Center of the Shade in its Path; which let it be M. At the Center M, with a Semidiameter, equal to the Semidiameter of the *Moon*, describe the Circle AFL: Also at the Center S, with a Semidiameter SB, equal to that of the *Sun*, describe the Circle EFG, which the Circle AFL cuts in E and F; then EBFA will be that Part of the *Sun*, which is covered by the *Moon* from a *Spectator* in S. For produce the Semidiameter of the *Moon* MA thro' S, that AD may be equal to the Semidiameter of the *Sun*, which is equal to BS; and then MD will be equal to the Sum of the Semidiameters of both *Sun* and *Moon*; and therefore it will be equal to the Semidiameter of the *Penumbra*: And the Distance of the Place from the Edge of the *Penumbra* is SD: And because BS is equal to AD, AB will be equal to SD. Take AN equal to the Semidiameter of the *Sun*, and

The Quantity of the Eclipse estimated by Digits.

Having the Position of the Place on the Disk, to find the Phasis of the Eclipse.

Plate X.  
Fig. 9.



Lecture XIII. and then MN will be equal to the Difference of the Semidiameters of the *Sun* and *Moon*, which is equal to the Semidiameter of the total Shadow. But we shewed, *pag.* 136, that SD was to DN, as AB the Part of the *Sun's* Diameter obscured was to the *Sun's* Diameter. But AB is equal to SD, and DN is equal to DA and AN, which are equal to two Semidiameters of the *Sun*, or to one Diameter of the *Sun*. Therefore AB is to the Diameter of the *Sun*, as SD, the Distance of the Place from the Edge of the *Penumbra*, is to DN, which is the Semidiameter of the *Penumbra* diminished by the Semidiameter of the total Shadow. And therefore it is plain, that AB must represent the Portion of the *Sun's* Diameter, which is then seen to be obscured.

HENCE also is determined the Position of the *Cuspides*, Points or Horns of the Eclipse; for by drawing the vertical Circle TSG, the Arches GE, GF, shew the Distance of the Points from the supreme or highest Point of the *Sun's* Limb.

IF the Velocity wherewith the Shadow goes over the Disk, be inquired for, it must be observed, that the Way of the *Moon* from the *Sun* is projected on the Disk, in a Line parallel and equal to itself; which Line is described by the Motion of the Shadow: And therefore the Velocity of the Center of the Shade is equal to the Motion of the *Moon* from the *Sun*. Now the Motion of the *Moon* from the *Sun* is about  $30\frac{1}{2}$  Minutes in an Hour; though it is sometimes more, and sometimes less. And therefore the Space, which the Center of the Shade moves through in an Hour, is about  $30\frac{1}{2}$  Minutes of the Lunar Orbit. Now the Semidiameter of the Lunar Orbit is about 60 Semidiameters of the *Earth*; and therefore one Minute of the Orbit of the *Moon* is as much as 60 on a great Circle of the *Earth*, or as much as one Degree, that is, 69 *English* Miles. And therefore  $30\frac{1}{2}$  Minutes are equivalent to 2104 *English* Miles; which Space the Shade moves through on the Disk in one Hour. But though this be the Velocity of the Shadow

The Velocity  
of the Shadow  
on the  
Disk,











Shadow on the Disk, yet the Velocity whereby the Shade recedes from any given Place on the *Earth's* Surface, is less than it; by reason that while the Shadow moves from the *East* to the *West*, all the Places of the *Earth* are likewise carried by the Rotation of the *Earth* the same Way: And therefore, following the Motion of the Shadow with a slower Pace, they diminish the Velocity whereby the Shade moves from them.

## LECTURE XIV.

*A new Method of computing Eclipses of the Sun, as they are to be observed from any given Place on the Earth's Surface.*



HERETO we have explained all the *Phases* and Appearances of a general Eclipse, such as a *Spectator* at the *Moon* would observe; and we have shewed the Methods whereby the Beginning, Middle, and End of an universal Eclipse may be determined. But this Beginning and End can be observed by only a few, who lie near the Edge of the Disk, where the Shadow enters. In other Places lying towards the Middle of the Disk, there will be no Eclipses seen, till some time after, when the Margin or Edge of the *Penumbra* comes to touch them. And the End will be when the opposite Part of the *Penumbra* leaves them. And therefore, according to the different Situation of Places, the Quantity of the visible Eclipses will be different, as likewise their Beginning, End, and Duration.

*The Beginning of an universal Eclipse can be observed by very few.*

*And the Beginnings in particular Places are very different.*

THEREFORE to compute the particular *Phases* of an Eclipse, as it is to be observed from a certain



Lecture XIV.  certain Place, we must here explain a new Method, whereby, without the troublesome and tedious Calculations of *Parallaxes*, which all the *Astronomers* have made use of before, the particular *Phases* may be shewn.

*A new Method to compute the Phases for a particular Place.*

Plate XI.  
Fig. 1.

LET therefore the Semicircle A E B, be half the Disk of the *Earth*, in whose Circumference is the Point E, which answers to the Pole of the *Ecliptick*. And let the Pole of the *Earth*, or the *Æquator*, be projected into P. Because all the Places of the *Earth*, being carried by the diurnal Rotation, describe Circles, which are the *Æquator* or its *Parallels*, and all the *Parallels*, except in the *Æquinoxes*, are inclined to the Plane of the Disk, the Parallel which any Place describes will be projected into an Ellipse, which will be the Way or Path in which that Place will be seen to move by a *Spectator* at the *Moon*. Let therefore F X I I D be the Ellipse in which the Parallel of any Place is projected on the Disk: And let the Points in which the *Horary* Circles cut the *Parallels*, be likewise projected: And let these Points be VI, VII, VIII, IX, X, XI, XII, I, II, III, IV, V, VI. So at Six in the Morning the Place on the *Earth's* Surface will be seen on the Disk at VI; at the seventh Hour it will be at VII, at Eight of the Clock it will be at VIII, and at Nine it will be in the Point IX, and so on.

LET CT be a Portion of the Path of the Shadow received on the Plane of the Disk: And suppose the Center of the Shade at Two of the Clock to be in the Point 2; at Three of the Clock let the Place of the Shadow be 3; and at Four let it be in the Point 4, &c. At Two of the Clock the Seat of the *Spectator* on the Disk is II; and therefore his Distance from the Center of the Shadow is 2 II: But if we measure this Distance according to the Path of the Shadow, we must let fall from the Place a Perpendicular to the Path, which let be II L, and the Distance thus estimated will be 2 L; and the Point L will be the Position of the Place reduced to the Path of the Shadow.

At



At Three of the Clock the Shadow is at 3, and the Place at III, and their Distance is 3 III, which is less than the former Distance at Two. At the fourth Hour the Shadow is in 4, and the Place in IV. All which Time the Shadow advances nearer to the Place, 'till at last the Edge of the *Penumbra* touches it, and then the Eclipse will begin at that Place. At the fifth Hour, when the Center of the Shadow is at 5, and the Place is in V, it will be there more within the *Penumbra* than it was before, and the Shadow will be near the Place: But at Six, the Shadow being at 6, and the Place at VI, the Shadow will have got to the *East* of the Place, which is then in the Point of the Disk at VI; and therefore the Center of the Shadow has passed by the Place, and the Time of the shortest Distance between the Center of the Shadow and the Place, will be between the Hours of 5 and 6. After this Time the Distance of the Shadow and Place will constantly grow greater, and at last the *Western* Edge of the *Penumbra* will leave the Place, and there will be an End of the Eclipse upon that Place. But by the following Method the Beginning, Middle, End and Duration of the Eclipse will be more accurately determined. Upon which Account we must first premise the two following Problems:

## PROBLEM I.

*To find upon the Disk of the Earth the Position of a Place for any given Point of Time.*

LET the Semicircle AEB represent half the Disk, AB a Portion of the Ecliptick projected on the Disk, its *Axis* projected SE, meeting with the *Periphery* of the Disk in E, which will be the Pole of the Ecliptick on the *Earth's* Surface. Let SP be the Line on which the *Axis* of the *Earth* is projected, and P the Projection of the Pole. As the *Radius* is to the *Sine* of the Latitude of the Place, so let SP be to SH, and the Point H will be the Pro-

Plate XI.  
Fig. 2.



Lecture XIV.  Projection of the Center of the Parallel. Through H draw H G equal to the Semidiameter of the Parallel, or to the *Sine* of the Distance of the Place from the Pole, which must be perpendicular to P S; this will be half the greatest *Axe* of the Ellipse into which the Parallel is projected. As the *Radius* is to the *Sine* of the Pole's Elevation above the Plane of the Disk, so let G H be to H L, and H L will be the lesser half *Axis* of the Ellipse. In G H take H Q, which has the same Proportion to G H, that the *Sine* of the Angle, which the Horary Circle and the Meridian make together, has to the *Radius*; and draw Q R perpendicular to G H: Also make the Proportion, as the *Radius* to the *Cofine* of the Angle which the Horary Circle and the Meridian make together, so the lesser *Semi-axe* H L to a fourth, to be laid on the Line Q R from Q to R; and then the Point R will be the Position of the Place on the Disk required at the Moment of the Time given.

THE same may be done by the Help of the Horary Circle.

Plate XI.  
Fig. 3.

LET A O B be half the Disk, P the Pole, S P the *Universal Meridian*, meeting with the Disk in G; and let F P O be the Horary Circle for the Moment of Time given. In the right-angled Triangle P G O, we have P G the Elevation of the Pole above the Disk, and the Angle G P O, which the Horary Circle makes with the Meridian; whence we shall find out the Angle G O P, the Inclination of the Horary Circle to the Plane of the Disk, and the Arches P O and G O; and therefore we have the Point O, where the Horary Circle cuts the Disk. Draw S O, which will be the common Section of the Horary Circle with the Plane of the Disk. Let P F be the Complement of the Latitude of the Place. And S O being the *Radius*, take S Q, equal to the *Sine* of an Arch, whose Complement is the Sum of two Arches that are known, *viz.* F P and P O; and let D be the *Cofine* of the same Arch whose *Sine* is S Q.



**S Q.** At Q upon O S erect the Perpendicular QR, so that D may have the same Proportion to QR, that the *Radius* has to the *Cosine* of the Inclination of the Horary Circle to the Plane of the Disk; and R will be the Point which was desired, and shews the Position of the Place on the Disk for the Time given.

The same Thing may be likewise found out this way: Calculate, (by the *Problems* demonstrated in the *Spherical Doctrine*, and in the *Problems* to be found where the Use of the Globes is taught) for the Moment of Time given, the *Sun's* Altitude, and the Angle between the Vertical and Hour-Circle at his Center, and make the Angle RSP equal thereto; and take SR equal to the *Sine* of the Complement of the Altitude, or the *Sine* of his Distance from the *Vertex*, SE being the *Radius*, and then R will be the Point required. By the same Methods, for all other different Moments of Time, we can find out other Positions of the Place on the Disk. The Demonstrations of all these Practices are easily deduced from the Laws of *Orthographical Projection*.

Plate XI.  
Fig. 2.

## PROBLEM II.

*To find in an Eclipse the Position of the Center of the Shadow on the Disk, for any given Time.*

LET AEB, as before, represent the *Semi-disk*, SE the *Axis* of the *Ecliptick*, CT the Path of the Shadow, while it passes over the Disk; and let it cut the *Axis* of the *Ecliptick* in N. Now when the Center of the Shadow is in N, then is the true Conjunction of the *Sun* and *Moon*, whose Time is known by *Astronomical Tables*. We have likewise by the same *Tables* the Horary Motion of the *Moon* from the *Sun*. Say, As the Horizontal *Parallax* of the *Moon*, is to the Horary Motion of the *Moon* from the *Sun*; so is the Semidiameter of the Disk to a fourth Line M: This will be the Space which the Shadow moves through upon the Disk

Plate XI.  
Fig. 4.



Lecture  
XIV.

 Disk in an Hour. Then say, As one Hour is to the Time between the Conjunction and the Time for which the Position of the Shadow is sought; so is the Line M to a fourth; this Line will shew the Distance of the Shadow in its proper Path, from the Point of Conjunction N, and consequently the Place of the Shadow for the Time given. Suppose the Hour which immediately precedes the Time of Conjunction, to be any Hour you please. For Example, let it be the fourth Hour; say, As one Hour is to the Time between the fourth Hour and the Time of the Conjunction, so let the Line M be to another, which is N 4; and the Point 4 will be the Position of the Shadow at four of the Clock. Take likewise 4 3, 3 2, 4 5, 5 6, equal to M; and the Points 2, 3, 4, 5, 6, will shew the Place of the Shadow at the Hours 2, 3, 4, 5 and 6.

Plate XI.  
Fig. 4.

*The Calcula-  
tion of the  
Beginning of  
the Eclipse.*

THESE things being premised, let A E B be half the Disk, as before, C T the Path of the Shadow upon the Plane of the Disk, which the *Axis* of the Ecliptick cuts in N; and when the Shadow comes to N, then is the Time of the true Conjunction. Let, for Example, the 2d be the Hour which immediately precedes the Time of the true Conjunction, and then mark in the Path of the Shadow its Places at the Hours 1, 2, 3, 4, 5; and likewise at the same Time mark the Situation of the Place on the Disk at the same Hours; let them be I, II, III, IV, V. At one of the Clock the Distance of the Place and Shadow is I I; this, by applying to a Scale of equal Parts, is to be measured, and taken in Numbers; and from thence deduct the Semidiameter of the *Penumbra* measured by the same Scale, and we have the Distance of the Place from the Edge of the *Penumbra*.

AT Two of the Clock, after the same Manner, take the Distance of the Edge of the *Penumbra* from the Place which is then in II; the Difference of these Distances, since the Edge of the *Penumbra* is in both Cases more *Westerly* than the Place, is the



the Appropinquation or relative Motion of the Place to the Shadow in one Hour. Say then, As the Appropinquation of the Margin of the *Penumbra* to the Place in one Hour is to the Distance of the said Margin from the Place at Two of the Clock, so one Hour is to the Distance of Time from Two till the Beginning of the Eclipse; which Time, added to the second Hour, shews the Time when the Eclipse begins.

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FROM the Position of the Place at II, to the Path of the Shadow, let fall the Perpendicular  $II\ a$ : And because the Center of the Shadow is at 2, the Distance of it from the Place reduced to the Path, is  $2\ a$ . Also at the third Hour the Position of the Place being III, let fall from thence a Perpendicular  $III\ b$  on the Path; the Distance of the Shadow from the Place reduced is  $3\ b$ ; the Difference of these two Distances is the Access of the Shadow to the Place reduced, in the Time of one Hour. Measure this Difference with a Scale, and by the Rule of Proportion say, As the Access of the Shadow to the Place reduced in one Hour, is to the Distance of the Shadow and Place reduced at three of the Clock; so is one Hour, or 60 Minutes, to a fourth Time; which Time, added to the third Hour, gives the Time of the Middle of the Eclipse, or of the greatest Obscuration.

*The Calculation of the Time of the greatest Obscuration.*

AT Four of the Clock the Center of the Shadow is in 4, and the Place in IV; and because IV is less than the Semidiameter of the *Penumbra*, subtract it from the Semidiameter, and there will remain the Distance of the Place from the Edge of the *Penumbra*. Again, at Five of the Clock the Shadow is in 5, and the Place in V; and their Distance is  $5\ V$ , which is greater than the Semidiameter of the *Penumbra*; and therefore the *Western* Edge of the *Penumbra* is now more advanced towards the *East*, than the Place is; and therefore before that time the *Penumbra* has quitted the Place, and the Eclipse at an End. From the Distance  $5\ V$ , subduct the Semidiameter of the *Penumbra*, and there will be left the Distance be-

*The Calculation of the End of the Eclipse.*

L

tween



Lecture XIV. *tween the Place and the Western Side of the Penumbra:* And because, in the former Case, at Four of the Clock, the Edge was *Westward* of the Place, and it has now got to the *East* of it, the relative Motion of the *Penumbra* and Place must be estimated by the Sum of these two Lines or Distances. Say then, As the Sum of these two Distances is to the Distance of the Edge of the *Penumbra* from the Place at the fourth Hour; so is one Hour to a fourth Time; which Time, added to Four, gives the Time when the *Penumbra* leaves the Place, or it will shew the End of the Eclipse.

THE Motion of the Shadow in its Path is equable, at least all the Time of an Eclipse it may be esteemed equable. But the Motion of a Place upon the Disk is no ways equable, but towards the Edge of the Disk it is slower; when it comes towards the Middle, it goes through larger Spaces in equal Time. Moreover, our Calculus supposes, that the relative Motion of the *Moon* and Shadow are equable; and the Middle of the Eclipse, or greatest Obscuration, to be where the Line which joins the Place, and the Center of the *Penumbra*, is perpendicular to the Path of the Shadow; neither of which is precisely true, and therefore there will arise some small Error; but it may be corrected in this Manner: At the Time of the Beginning of the Eclipse, find out the Place of the Shadow, and likewise, for the same Time, the Situation of the Place upon the Disk. At the Center of the Shadow, with a Distance equal to the Semidiameter of the *Penumbra*, describe a Circle: If this Circle passes through the Point the Place is in, then is the Beginning of the Eclipse rightly determined; but if this Circle does not pass through the Place, note the Distance of the Place and the *Periphery*, and take the relative Motion of the Place and Margin of the *Penumbra* for half an Hour; and work again by the Rule of Proportion, as before, and we shall then have the true Time of the Beginning of the Eclipse. And by the same Method



Method we may correct the Error, that may arise in computing the End of the Eclipse. And by this means we may have the Beginning and End of Eclipses, as accurately as by the common Method, which is by a troublesome Calculation of the *Parallaxes*; where they likewise suppose, that the visible Motion of the *Moon* is equable for a certain Time; which, nevertheless, is as unequable as the Motion of a Place upon the Disk is.

IF about the Time of the middle of the Eclipse, at the Center of the Shadow, a Circle be described, whose *Radius* is equal to the Semidiameter of the *Moon*; and if likewise we describe another Circle, whose Center is the Place of the *Spectator*, and whose *Radius* is the Semidiameter of the *Sun*; the Intersections of these two Circles will shew the *Phasis* at the greatest Obscuration.

IF there be some who are not pleased with this mechanical Way of measuring Lines and Distances by a Scale, they may compute all the Lines by *Trigonometry*, in the following Manner: As before, let AEB be the Disk of the *Earth*, P the Projection of the *Pole*, CNT the Way of the Shadow, the Point 2 its Position at Two of the Clock; and, for the same Time, let II be the Situation of the Place of the *Spectator*. Let SE be the *Axis* of the *Ecliptick*, which cuts the Path of the Shadow in N; SN will be the Latitude of the *Moon* at the Time of the *Conjunction*. From the Center of the Shadow and the Place draw the Line 2S, II S, to the Center of the Disk, and join 2II: Then in the right-lined Triangle 2NS we have NS the Latitude of the *Moon*, and 2N its Distance from *Conjunction* at Two of the Clock. We have likewise the Angle 2NS, which is the Inclination of the Path to the Circle of Latitude: Wherefore we can find out 2S, and the Angle 2SN. Again, in the spherical Triangle PSII, we have the Side PS the Complement of the *Sun's* Declination, and PII the Complement of the Latitude, together with the Angle SPII, which is known by the Time; by which we can find the



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Arch  $S II$ , which is the Distance of the *Sun* from the *Vertex*; and the *Sine* of this Arch is just equal to the Distance  $S II$ ,  $S E$  being made the *Radius*: We may also find the Angle  $PS II$ ; to which if we add, or take away the known Angle  $PS E$ , we shall have the Angle  $NS II$ . But the Angle  $2 S N$  was found out before; wherefore we have the whole Angle  $2 S II$ . Lastly, in the Right-lined Triangle  $2 S II$ , we have the two Sides  $2 S$  and  $II S$ , and the Angle contained between the two Sides; and therefore by plain Trigonometry we may find the Side  $2 II$ , which was to be found out. Proceeding by this Method, there is no need for inquiring into the Positions of Place and Shadow on the Disk; for they are to be found out by a *Calculus* without Protraction.

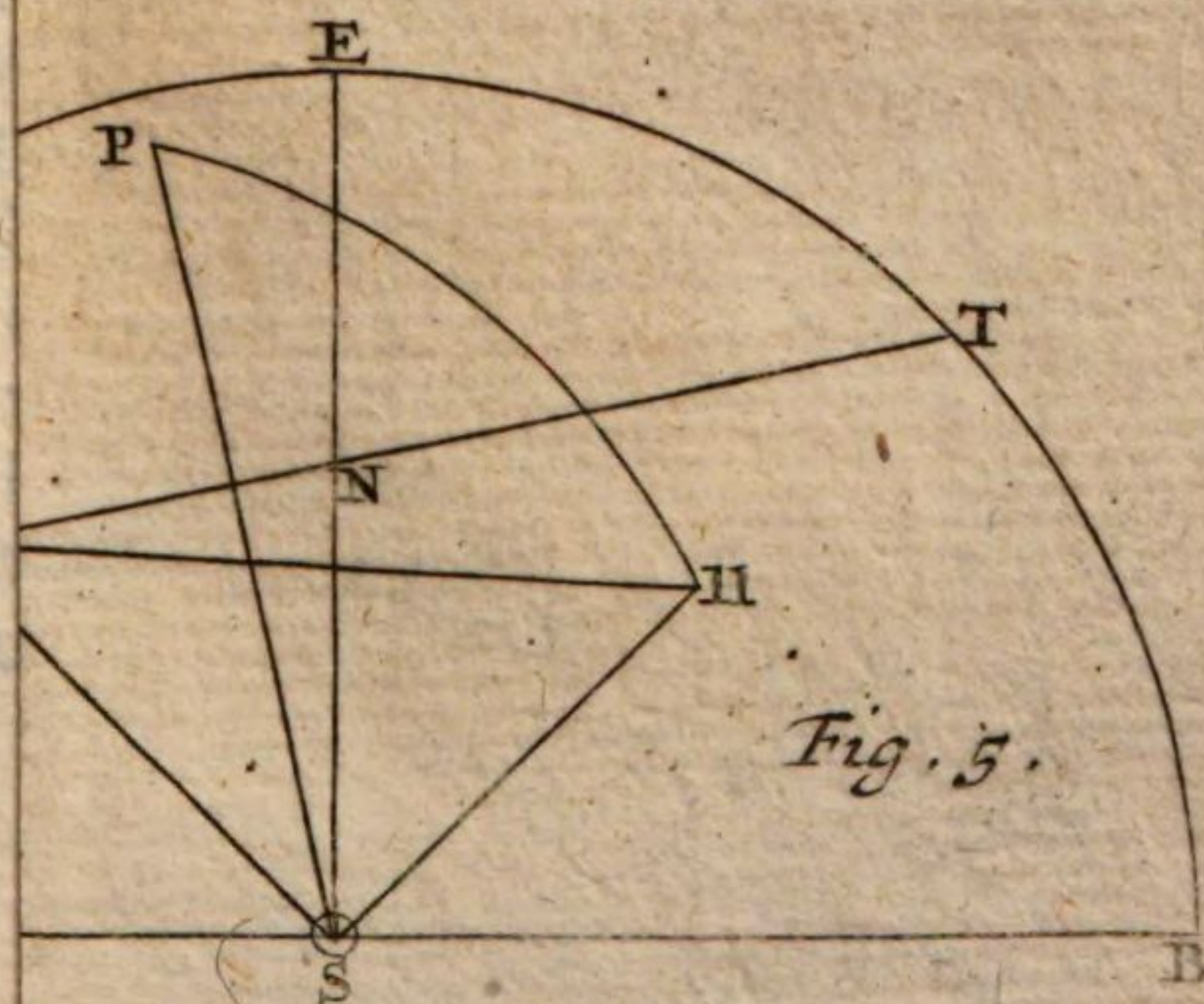
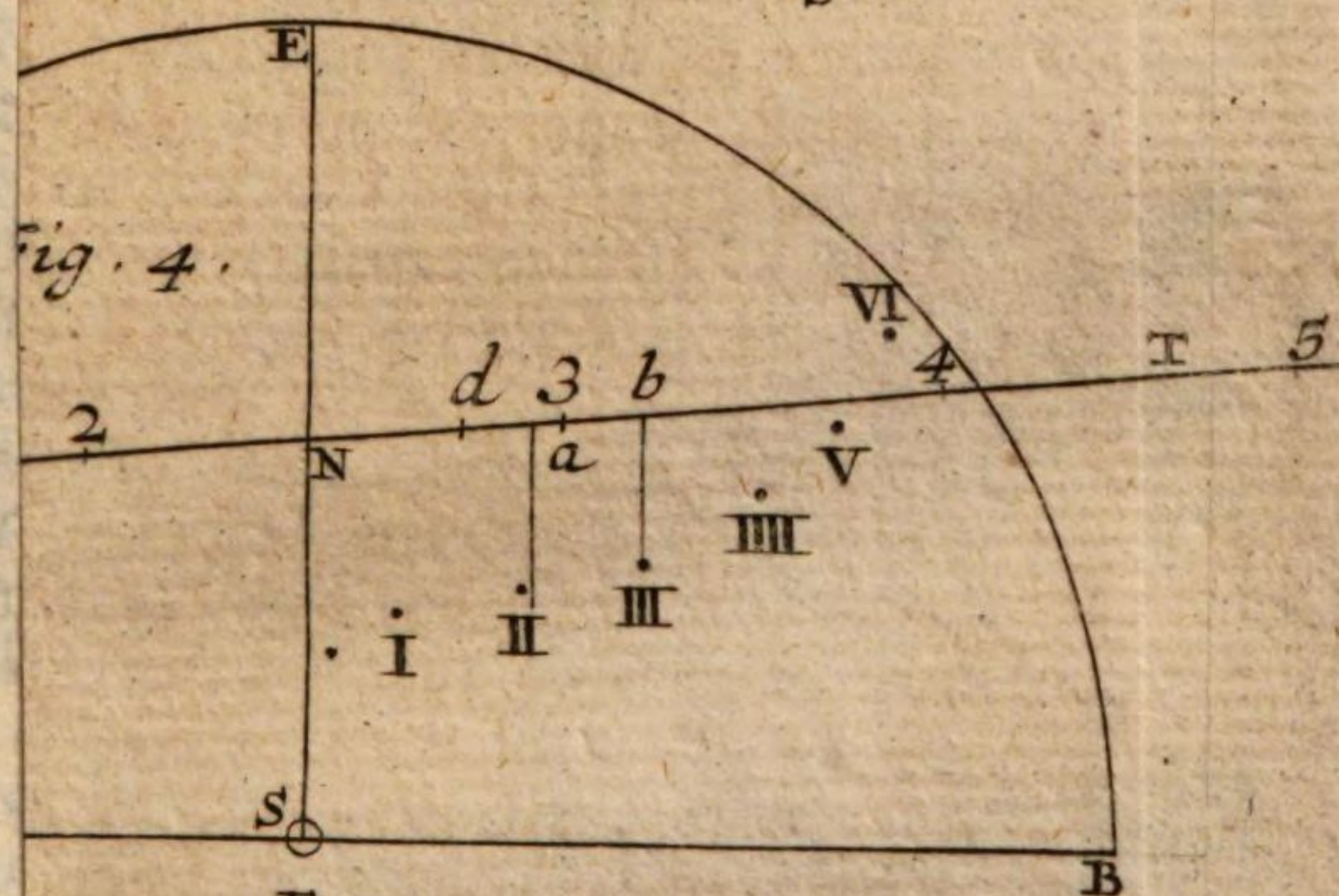
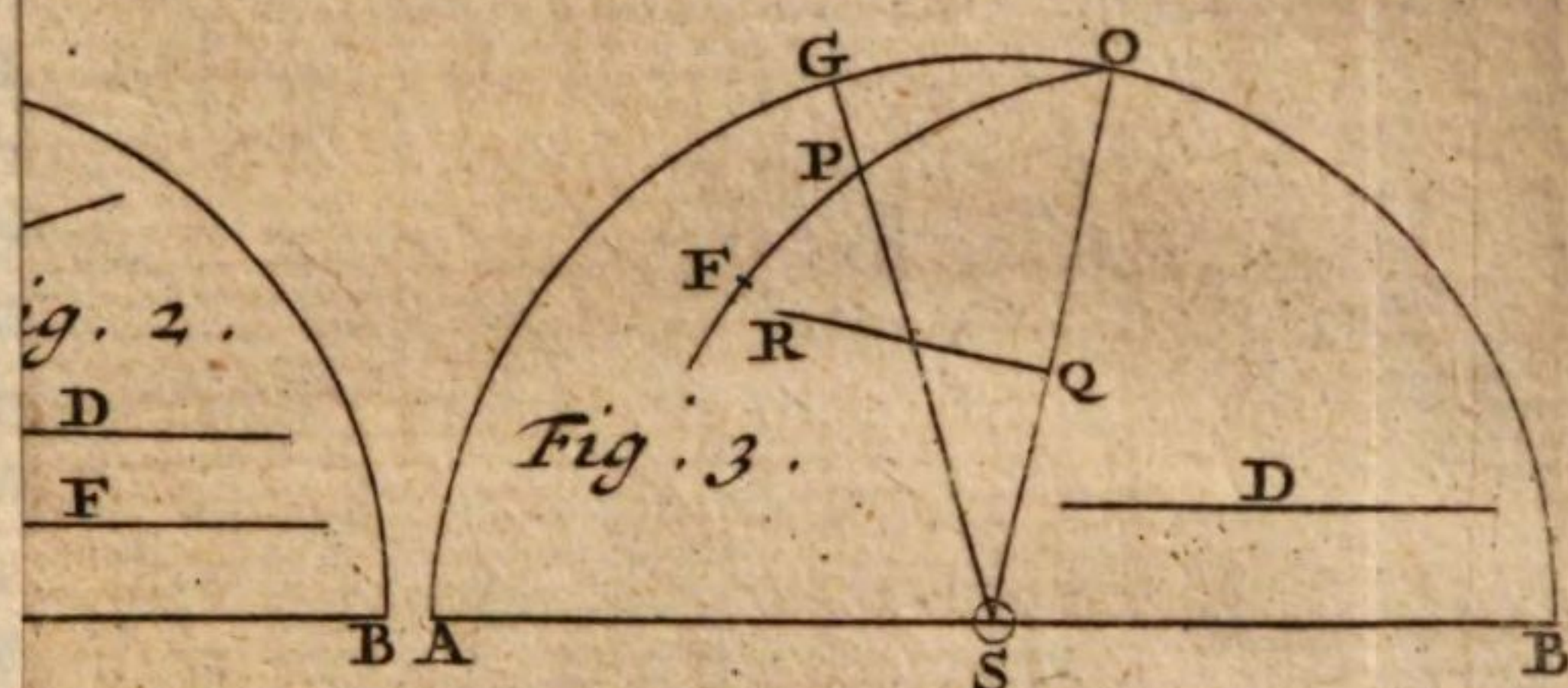
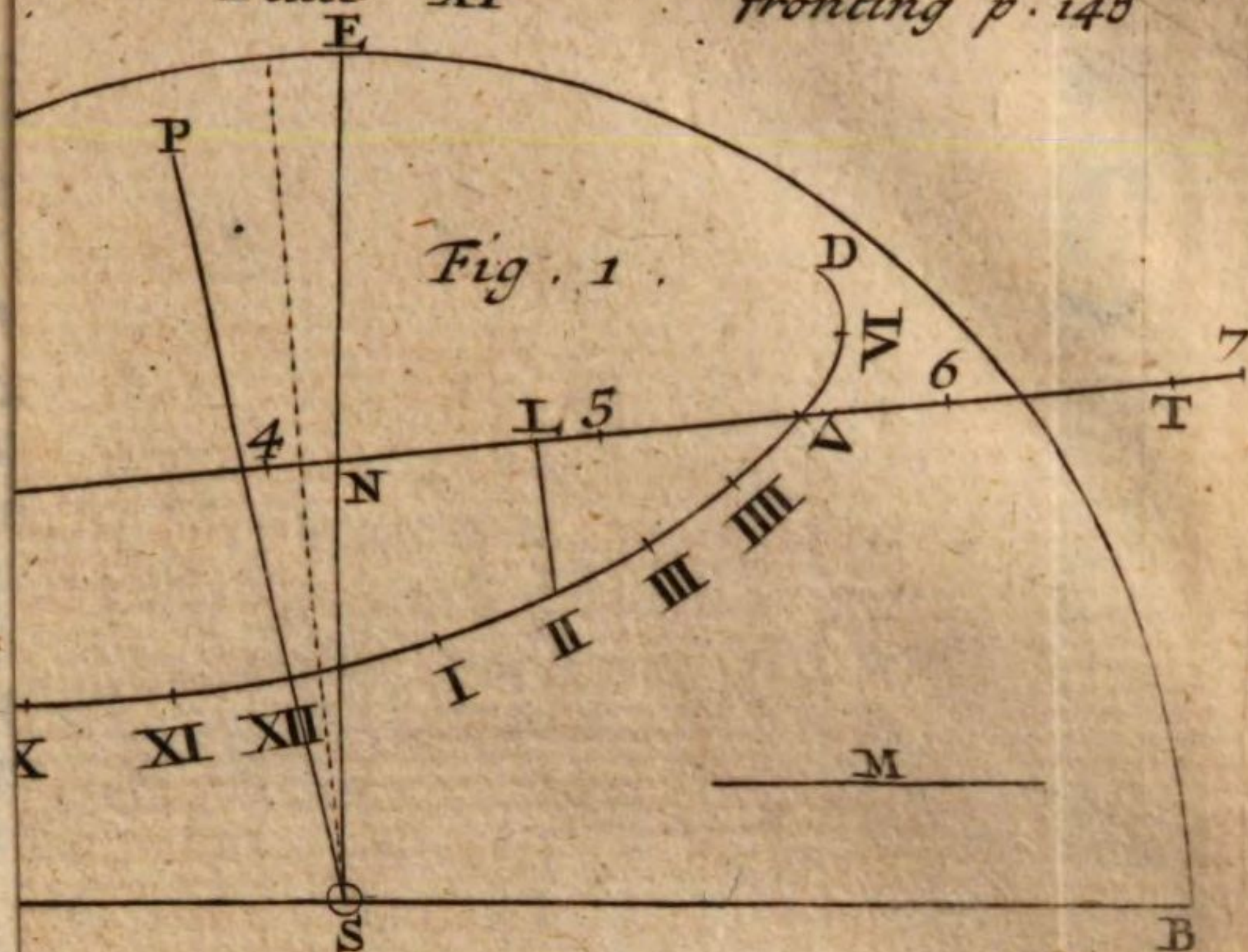
To find the  
Longitude of  
Places by  
Observations  
of Solar  
Eclipses.

Plate [XI.  
Fig. 2.

THE Longitudes of Places on the Surface of the *Earth* may be found out by Observations of Eclipses of the *Sun*, as well as by those of the *Moon*, viz. if we observe in that Place whose Longitude is wanted, the Moment of Time when the Eclipse begins or ends. Let that, for Example, be at Five of the Clock; and at the Center  $V$ , with a Distance equal to the Semidiameter of the *Penumbra*, describe an Arch of a Circle cutting the Path of the Shadow in  $d$ : that Point  $d$  will shew the Place of the Center of the Shadow at that Time. Measure the Distance  $N d$  with a Scale, which being given, together with the Motion of the *Moon* from the *Sun*, we shall find the Time in the Place of the Observation, when the true *Conjunction* is celebrated. In like Manner, by an Observation in any other Place, we may find when the same *Conjunction* is celebrated according to the Time computed from the Meridian of that Place; and the Difference of those Times being turned into Degrees and Minutes of the *Æquator*, will shew the Difference of Longitude between those two Places.

IN Practice it is convenient to make the Semidiameter of the Disk ten Inches, that it may be divided by a Scale into 1000 Parts; which is  
done











done by the Help of a Diagonal Scale; for this Number is the *Tabular Radius*: And let SN the Latitude of the *Moon*, and all the Lines whose Dimensions are necessary to be known, be expressed by the same Parts. For if we say, As the Horizontal *Parallax* of the *Moon*, which is expressed in Astronomical Tables in Minutes and Seconds, is to the *Moon's* Latitude, so is 1000 to a fourth Number; and then we take the Line SN out of the Scale, whose Dimension is expressed by this fourth; this Line will represent the Latitude of the *Moon*. And in like manner, we are to operate to find out the Length of the Way the Shadow advances in an Hour in its Path. And now we have shewed a new Way, by which the Times and *Phases* of an Eclipse are to be defined, as they are to be seen from a particular Place, which does not require a frequent or repeated Calculation of the *Parallax*, to have the visible Place of the *Moon* in the Heavens, both as to Longitude or Latitude; which Method is received by most *Astronomers*. But our Method is much easier, and, as I think, no less accurate: For in the common Method the different Positions of the Ecliptick in respect of the Horizon, which are always changing, will produce great Inequalities in the *Moon's* Motion, and will make her constantly alter her Place, both as to Longitude and Latitude: So likewise as the *Moon* ascends or descends, the *Parallaxes* will always be changeable; and except we often compute them, it will be hard to escape falling into an Error.

BUT because the Method of computing Eclipses by *Parallaxes*, is that which is generally made use of by the *Astronomers*, it will be convenient likewise to explain that Method. And here I suppose the Reader to be already instructed in the Doctrine of the *Parallaxes*, either by other Astronomical Books, where it is explained at Length; or by what we shall after this say upon that Subject: And that being understood, the Principles on which the Calculation is founded are easily apprehended,



Lecture hended, though the Practice of the Rules is very  
XIV. difficult and tedious.

*The common  
Method of  
computing  
Eclipses of  
the Sun.*

Plate XII.  
Fig. 1.

*The Moon's  
true Place.*

*The Moon's  
visible  
Place.*

*The Moon's  
Parallax.*

FIRST of all, the visible *Conjunction*, and the Way the *Moon* is then to take in the Heavens, are to be determined. For in this Case, the true and visible *Conjunction* are very different both as to their Times and Places. The true Place of the *Moon* is that which is seen from the Center of the *Earth*, the visible Place is that which is seen from our Habitation on its Surface. Let the Semicircle ABC represent an Hemisphere of the Globe of the *Earth*, whose Center is T; from whence draw the Right Line T L S through the *Moon* at L, and the *Sun* at S, at a much greater Distance; and therefore since the Centers of the *Sun* and *Moon* are seen in the same Right Line from the Center of the *Earth*, they will appear in the same Point of the Heavens, and they will be in true *Conjunction*. But a *Spectator*, on the Surface of the *Earth* at A, will observe the Centers of the *Sun* and *Moon* in distinct Points of the Heavens, their Distance being the Arch S E. The Point where the Right Line T L, drawn through the Centers of the *Earth* and *Moon*, meets with the Heavens, is called the true Place of the *Moon*. But where a Right Line passing through the Eye of the *Spectator* on the Surface, and the Center of the *Moon*, meets with the Heavens, that Point is called the visible or apparent Place of the *Moon*. Let these Points be S and E; the Arch S E, which is the Distance between the true and apparent Place, is called the *Moon's Parallax*. Now because the Points T and L, in respect of the immense Distance of the *fix'd Stars*, coincide, the Arch S E will be the same, whether its Center be conceived to be in L, or in T; and therefore the Arch S E is the Measure of the Angle S L E, or of the Angle A L T, which is equal to it. But the Angle A L T is the Angle under which the Semidiameter of the *Earth* A T, drawn thro' the Place of the *Spectator*, is seen from the *Moon*: And therefore the *Parallax* of the *Moon* is always equal to this Angle. And this Angle is biggest,



biggest, when the Semidiameter is directly seen from the *Moon*; for then the Angle  $LAT$  is a Right Angle, and the *Moon* is seen in the Horizon, and therefore the *Horizontal Parallax* is greatest of all. But if the *Moon* should be in the *Vertex*  $F$ , the Angle  $LAT$  would there vanish; and the *Moon's* true Place would coincide with its apparent Place, whence there would be no *Parallax*.

SINCE the *Parallax* of any celestial Body is always equal to the Angle under which the Semidiameter of the *Earth*, passing through the Place of the *Spectator*, is seen from that Body, there will be no sensible *Parallax* of the *Sun*. For, as I have frequently said, the *Earth* seen from the *Sun* appears no bigger than a Point, and under no sensible Angle: But the *Moon*, when it is in the Horizon, has a sensible *Parallax*, and sometimes it is greater than a Degree.

The Sun  
has no Par-  
allax.

HENCE it follows, that the *Parallax* always shews the *Moon* more depressed, or at greater Distance from our *Vertex*, than it really is: This Depression will change its Place according to the *Ecliptick*, and make the *Moon* appear to have a Longitude and Latitude different from what it has, when seen from the Center of the *Earth*. For in Plate XII, the Figure, let the Circle  $HCZ$  be the Meridian, or the Circle passing through the *Vertex* of the *Spectator* and the *Pole*; let  $Z$  be the *Vertex*,  $HE$  the *Horizon* of the Place,  $CE$  the *Ecliptick*; in which let the *Moon* according to its true Place be in  $L$ , without any Latitude; let  $ZT$  be a Vertical Circle passing through the *Moon*; and because the *Parallax* always depresses the *Moon* in the Vertical, the apparent Place of the *Moon* will be further distant from the *Vertex*  $Z$ , than the true Place is. Let the apparent Place be  $O$ , and since the true Place is  $L$ , the *Parallax* will be  $LO$ ; which being in the Vertical, or Circle of Altitude, is called the *Parallax* of Altitude. Through  $O$  let there a Circle pass, which is perpendicular to the *Ecliptick*, meeting with the *Ecliptick* in  $m$ : That Point will be the apparent Place reduced to the

Plate XII,  
Fig. 2.



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Ecliptick, and the Arch  $Lm$  is called the *Parallax of Longitude*; and  $Om$ , the visible Distance of the *Moon* from the Ecliptick, is called the *Moon's Parallax of Latitude*. For determining the *Phases* of Eclipses, as they are to be seen from a given Place, it is necessary to know at that Time the true Places of the *Moon* and *Sun*, which may be computed by Astronomical Tables from any given Moment of Time. Moreover, we must know the apparent Place of the *Moon*, which is to be determined from a true Place, by a Computation of the *Moon's Parallax*; which being premised, the Times and *Phases* are thus found out.

Plate XII.  
Fig. 3.

A Calcula-  
tion of the  
visible Ec-  
lipse.

LET  $pk$  be a Portion of the Ecliptick;  $S$  the Place of the *Sun* therein, at the Time of the true *Conjunction*; and  $l$  the apparent Place of the *Moon* reduced to the Ecliptick;  $lo$  the visible Latitude of the *Moon*, and  $lS$  will be its visible Longitude from the *Sun*. At a small Portion of Time before the true *Conjunction*, find out again the visible Place of the *Moon* in the Ecliptick; which let it be at  $p$ , and let  $pq$  be the *Moon's* visible Latitude: Draw  $qo$ , which produce, and let it meet with the Ecliptick in  $k$ ; and  $qk$  will be the visible Way of the *Moon* from the *Sun* at the Time of the *Conjunction*. In the Triangle  $qon$ , right-angled at  $n$ , we have  $on$  the Difference of Longitude of the *Moon* from the *Sun* in  $p$  and  $l$ , and  $qn$  the Difference of Latitude; whereby we can find the Angle  $qon$ , or  $qkp$ , which is equal to it, and which is the Inclination of the visible Way of the *Moon* to the Ecliptick. From thence also we can find the Side  $qo$ , and by them we can find the Lines  $ot$ ,  $tk$ ,  $Sk$ , and  $St$ . For  $pl$  is to  $qo$ , as  $ls$  is to  $ot$ : And in the Triangle  $olk$ , by having  $ol$  and the Angle  $k$ , we can find  $ok$  and  $lk$ , and thereby  $Sk$ , and  $St$ . Now, when the Center of the *Moon* is seen at  $t$ , then is the visible *Conjunction* of the *Sun* and *Moon*. And therefore we say, As  $qo$  is to  $ot$ , or as  $pl$  is to  $lS$ , so is the Time that the *Moon* moves through the Space  $qo$ , to the Time it moves through  $ot$ ; and then we shall have the  
Time



Time between the true and visible *Conjunction*. From  $S$  upon the Way of the *Moon* let fall a Perpendicular  $Sm$ , and in the Right-angled Triangle  $Sk m$ , we have  $Sk$  and the Angle  $k$ ; therefore we can find out  $Sm$ , which is the least visible Distance, or the nearest Approach of both *Sun* and *Moon*. If this Distance be greater than the Sum of the Semidiameters of the *Sun* and *Moon*, there will be no Eclipse visible in that Place; but if it be less, the Difference reduced into Digits will shew the Quantity of the Eclipse. Having the Side  $Sm$ , and the Angle  $tSm$ , which is equal to the Angle  $k$ , we can find out the Line  $tm$ , and thence the Time the *Moon*, in her visible Way, takes to describe the Line  $tm$ , which is the Time between the visible *Conjunction*, and the Moment of greatest Obscuration.

THE Beginning of the Eclipse is thus deter- Plate XII.  
mined: Let  $pk$  be a Portion of the Ecliptick, as Fig. 4.  
before;  $S$  the Center of the *Sun*; let  $qk$  be the  
visible Way of the *Moon*,  $Sm$  its shortest Distance  
from the *Sun*. Draw from the *Sun* to the Way of  
the *Moon*, the Right Line  $sq$ , equal to the Semidi-  
ameters of both *Sun* and *Moon*: And then, when  
the Center of the *Moon* comes to  $q$ , the Eclipse  
will begin to be visible, and the two Margins of  
the *Sun* and *Moon* will seem to touch one another.  
In the rectangled Triangle  $qSm$ , we have the  
Side  $Sq$ , equal to the Sum of the Semidiameters of  
the *Sun* and *Moon*, and  $Sm$  the nearest Approach  
of their Centers; from whence we can find out  
the Angle  $qSm$ , the Angle of Incidence, and also  
the Side  $qm$ ; and thereby we have the Time where-  
in the *Moon* describes the Line  $qm$ , and from thence  
the Time between the Beginning of the Eclipse  
and the Time of the greatest Obscuration.

AFTER the same Method we may find the  
Time of the visible End of the Eclipse. But here  
we must begin again, and compute anew, by the  
*Parallaxes*, the visible Way of the *Moon* from the  
*Sun*, after the *Conjunction*, which will not be the  
same it was before. For the Inclination of the  
visible



Lecture XIV.  visible Way is constantly changing, because the Quantity of the *Parallax* is in perpetual Flux, as the *Moon* rises and falls in Altitude. Seek therefore, about an Hour after the *Conjunction*, the visible Longitude of the *Moon* from the *Sun*, and its visible Latitude, and from them compute the Inclination of the *Moon's* Way from the *Sun*; which being found, by the same Method we found the Time of the Beginning of the Eclipse, we may likewise find the Time of its End.

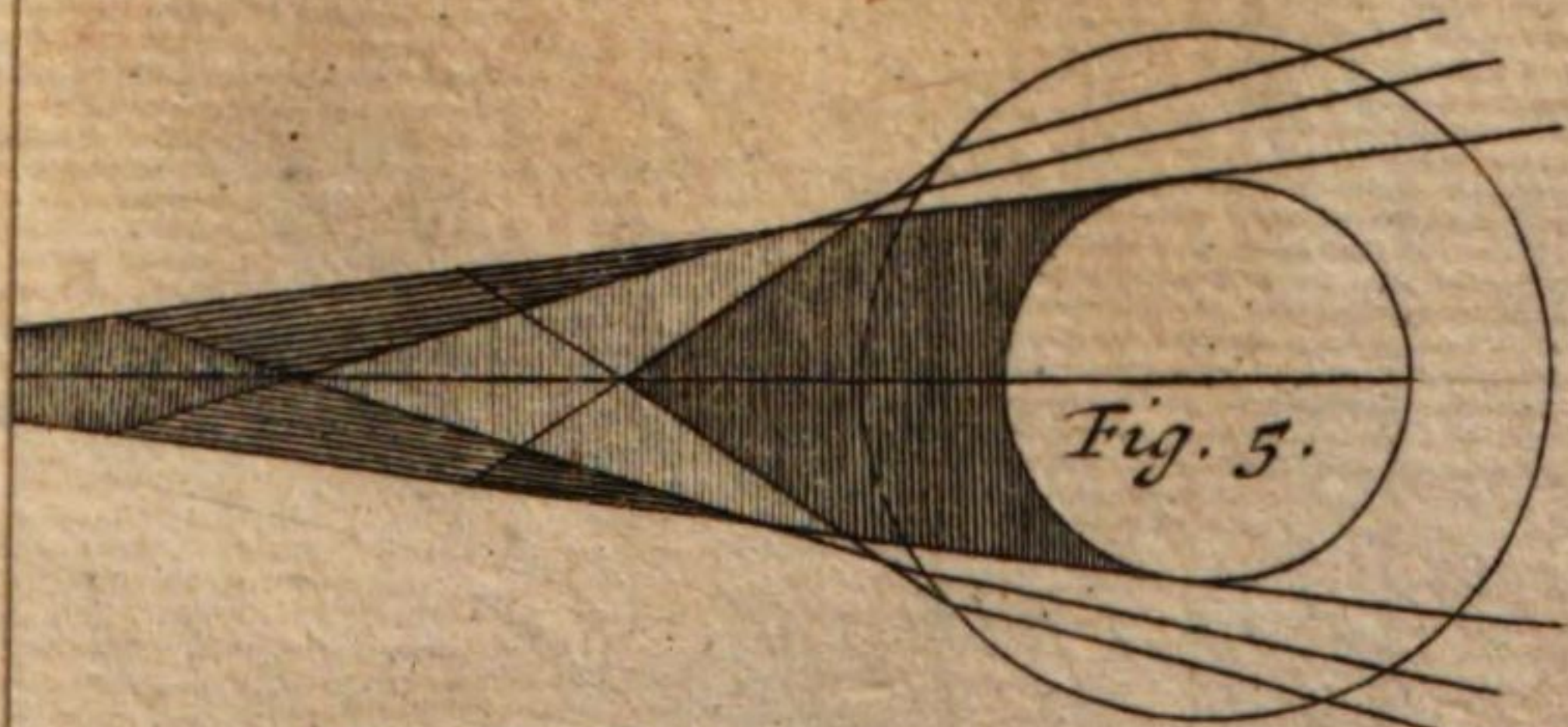
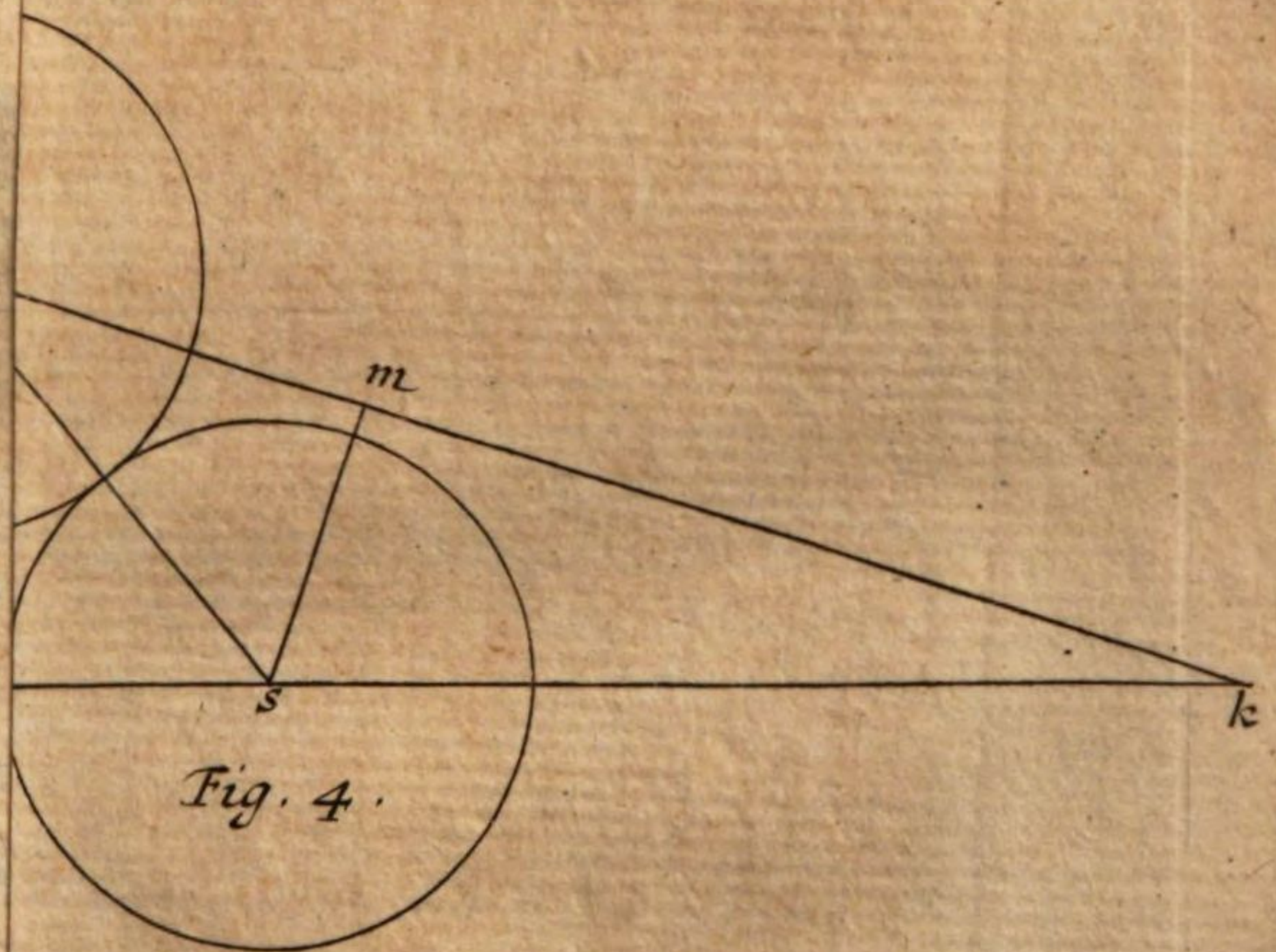
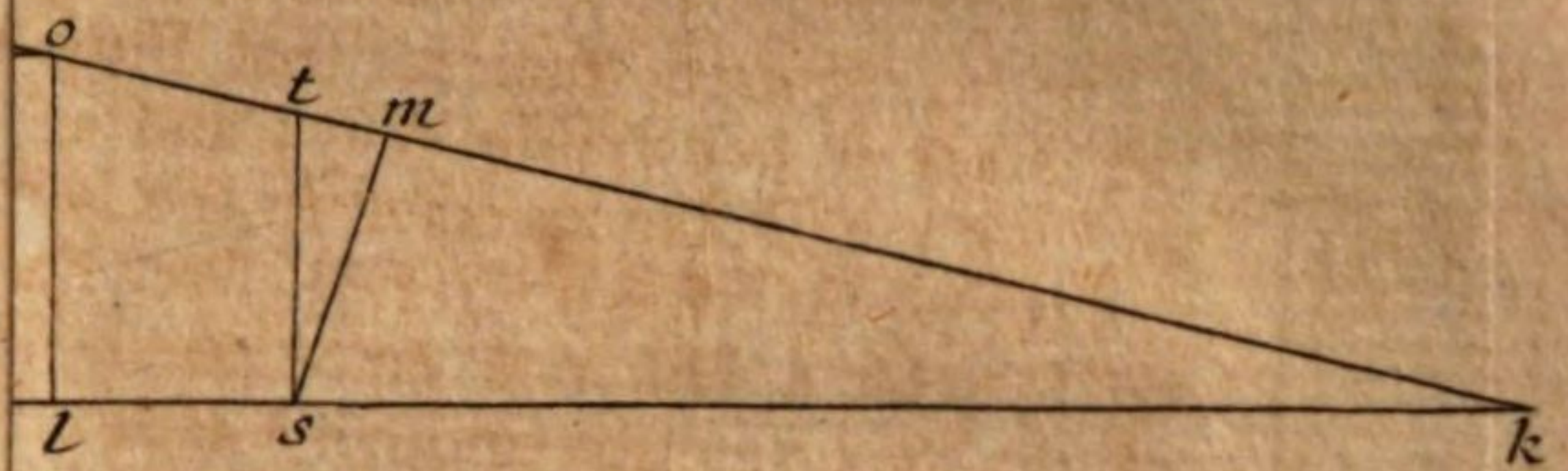
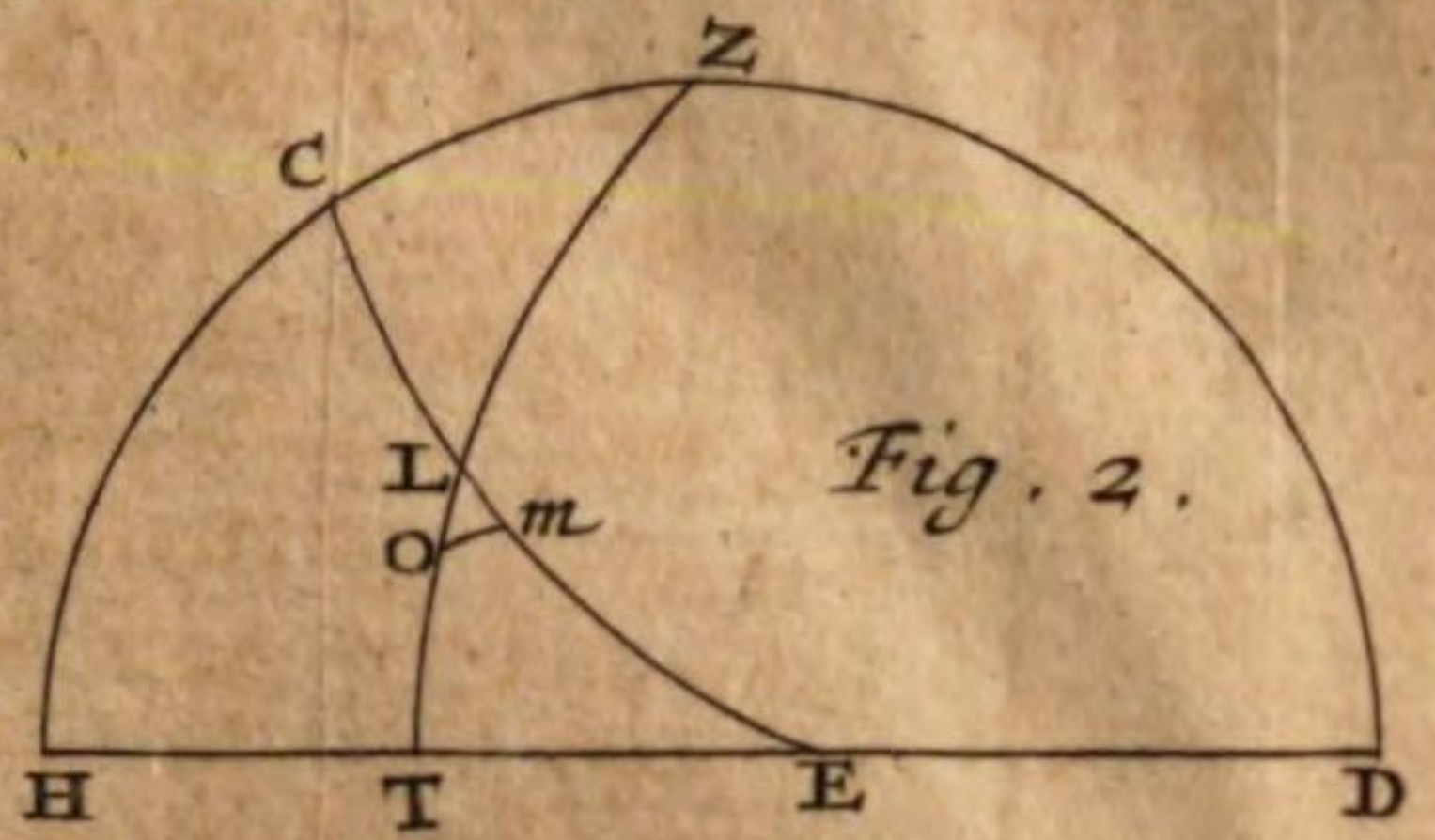
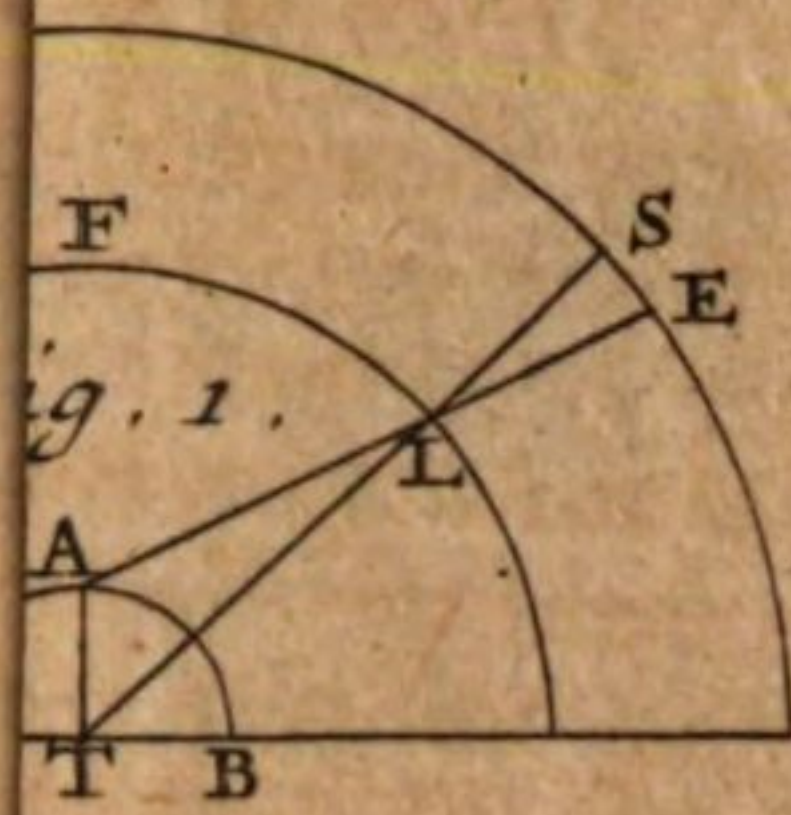
*A Determination of the Phasis for any Moment of Time.*

IF the *Phasis* of an Eclipse for any Moment of Time be required, find for that Time the Place of the *Moon* in her visible Way; and at that Center, and with a Distance equal to the Semidiameter of the *Moon*, describe a Circle; likewise at the Center *S*, with a Distance equal to the Semidiameter of the *Sun*, describe another Circle; the Intersections of these two Circles will shew the *Phasis* of the Eclipse, and the Quantity of Obscuration, as also the Position of the Cusps or Horns.

BEFORE we make an End of this Doctrine of Eclipses, it will be requisite to explain one notable Appearance, and to shew the Reason of it.

IN total Eclipses of the *Moon*, even when she is near the Center of the Shadow, her Body is frequently to be seen of a pale and languid Colour, which could not be without her being illuminated with some Light; and some will wonder from whence arises this Light. Some suspected that it was the native and proper Light of the *Moon* herself. Others derived it from the *Planets* and *Stars*; for the Interposition of the *Earth* intercepts all the Light of the *Sun*, and seems to bring a thick Darkness upon the whole Space taken up by the conical Shadow. But we must consider, that the *Earth* is surrounded with a Sphere of Air of a considerable Depth and Density, which has a refractive Power, whereby it turns the Rays of the *Sun* out of their Way when they fall upon it, and makes them enter the conical Shadow; which therefore will be illuminated by that small Quantity



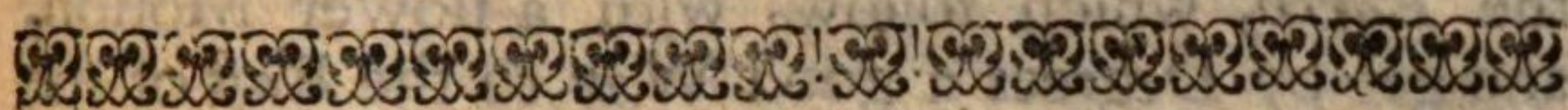








tity of Light which falls obliquely on our Atmosphere, and imparts to all the Bodies within it a faint Light, the which will illuminate the *Moon*, even when it is in the midst of the Shadow, and make it visible to our Eyes, as the Figure shews. Lecture XV.  Plate XII. Fig. 5.



## LECTURE XV.

*Of the Phænomena or Appearances arising from the Motions of the Earth, and the two inferior Planets Venus and Mercury.*



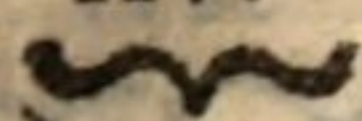
HERETO we have contemplated the Motions of the *Earth* and *Moon*, and have given an Account of many Appearances that arise from them. The *Moon* indeed is no primary Planet, but a secondary, which does no other ways go round the *Sun*, the true Center of our System, than by accompanying our *Earth*, to whom she properly belongs, in her annual Course round the *Sun*.

BUT the chief and primary Planets of our System, which perform their Circulations round the *Sun*, without regarding any other Body, are in Number six, viz. *Mercury* ☿, *Venus* ♀, the *Earth* ⊕, *Mars* ♂, *Jupiter* ♃, and *Saturn* ♄, whose Motions and Appearances are now to be explained. And, first, we have already demonstrated, that the Orbits of *Venus* and *Mercury* include the *Sun*, and that they are included within the Orbit of the *Earth*; and since they finish their Circulations in less Time than the *Earth* does, it is manifest that these Planets, seen from the *Sun*, will appear

*The six primary Planets.*



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appear in the Heavens sometimes nearer, and sometimes further from the *Earth*; and that sometimes they may from thence appear in the same Point, and sometimes in opposite Points of the Heavens, with the *Earth*. And because *Venus* and *Mercury* are carried faster about than the *Earth*, a *Spectator* in the *Sun*, after seeing either of them in *Conjunction* with the *Earth*, will see it recede from the *Earth*, which follows with a slower Motion, and get by Degrees a good Way to the *East* of the *Sun*.

Two Cases  
of Conjunctions.

Plate XIII.  
Fig. 1.

As these *Planets*, seen from the *Sun*, change their Positions in respect to the *Earth*, so likewise we, seeing them from the *Earth*, observe that they change their Positions in respect to the *Sun*, and are sometimes nearer, sometimes further removed from him; and sometimes they appear in *Conjunction* with the *Sun*. But the *Conjunctions* of these *Planets* seen from the *Earth*, do not only happen when the *Earth* and they are seen together in *Conjunction* from the *Sun*, but also when a *Spectator* in the *Sun* sees the *Earth* and them in *Opposition*: Even then the *Sun* and they, seen from the *Earth*, appear to be in *Conjunction*. For let S be the *Sun*, ABC the Orbit of the *Earth*, FHV the Orbit of *Venus*; and let the *Earth* be in T, and *Venus* in V, in the Line which joins the Centers of the *Earth* and *Sun*: In this Position *Venus*, seen out of the *Sun*, is in *Conjunction* with the *Earth*, as the *Sun* from the *Earth* is seen conjoined with *Venus*.

BUT if the *Earth* were in T, and *Venus* in F, a *Spectator* in the *Sun* will see *Venus* and the *Earth* in *Opposition*, or in opposite Points of the Heavens. But a *Spectator* in the *Earth* will see *Venus* not in *Opposition* to the *Sun*, but in *Conjunction* with him. In the first Case of these *Conjunctions*, *Venus* is between the *Sun* and the *Earth*; in the other the *Sun* is situated between the *Earth* and *Venus*; and *Venus* goes above the *Sun*: The first is called the *inferior Conjunction*, the second the *superior*.

AFTER



AFTER either of these two Sorts of *Conjunctions*, *Venus* will seem daily to remove further from the Neighbourhood of the *Sun*, and will daily seem to get further off from him; but still she keeps within certain Bounds, for she never comes to be opposite to the *Sun*; nor does she even arrive at a *Quadrantile Aspect*, which is 90 Degrees; or a *Sex-tile Aspect*, which is 60 Degrees distant from the *Sun*. And *Venus* is seen at her greatest Distance from the *Sun*, when the Line which joins her Center with the *Earth*, touches the Orb of *Venus*, as about D. For when this *Planet* is farther advanced to H, its Place in the Heavens is seen to be nearer to the *Sun*, than it was before at D. Now before she came to D, she always receded more and more from the *Sun*: And after she has left D, she every Day comes nearer to the *Sun*: It is necessary, that between the Times of her Recess and Approach, she become stationary in respect to the *Sun*, and for some time appear to keep the same Distance from him; at which Time the visible Motion of *Venus* will be equal to that of the *Sun*. The Arch of a great Circle, intercepted between *Venus* and the *Sun*, is called the *Elongation* of that *Planet* from the *Sun*.

*The Elonga-  
tion of a Pla-  
net from the  
Sun.*

BUT here it is to be observed, that only in a Circle, which has the *Sun* for its Center, the greatest *Elongation* happens, when the Right Line which joins the *Earth* and *Planet* touches. For in an Elliptick Orbit it may be, that the *Elongation* from the *Sun* may grow still greater, even after it has left the Place where the Line joining the *Earth* and *Planet* touches its Orbit: For after that, the true Distance of the *Planet* from the *Sun* may increase, whilst the Distance of the *Sun* and *Planet* from the *Earth* does not increase, but they may rather decrease. And therefore in two Triangles, the greater Base will subtend the greater Angle. But because the Orbits of the *Planets* are nearly circular, such small Differences may be here neglected.

*The Elonga-  
tion is not al-  
ways great-  
est, when it  
is in a Line  
touching the  
Planets Or-  
bit.*



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XV.

THE greatest Elongation of *Venus* is found by Observation to be about 48 Degrees, by which, in a circular Orbit, we may know the Distance of *Venus* from the *Sun*, in respect of the *Earth's* Distance from the same: For  $ST$  is to  $SD$ , as the *Radius* is to the *Sine* of the Angle  $STD$ , which is the greatest Elongation.

HENCE also it is manifest, that *Venus*, from the Time of her superior *Conjunction*, where she is furthest from the *Earth*, to the Time of her inferior *Conjunction* with the *Sun*, where she approaches nearest it, is always seen more *Easterly* than the *Sun*; and all that Time *Venus* sets later than the *Sun*, and is seen after Sun-setting; and then she is called the *Evening-Star* or *Vesperus*, being a Fore-runner of Night and Darkness. But from the inferior *Conjunction*, till she comes again to the superior, she is always observed to be to the *Westward* of the *Sun*, and consequently must set before him in the Evening, and rise before him in the Morning, and then she is only to be seen before Sun-rising; when she is called the *Morning-Star* or *Phosphorus*, her Appearance foretelling that Light and Day are at Hand.

LET us now suppose *Venus* and the *Earth* to be seen out of the *Sun* in *Conjunction*, and the one to be at  $V$ , the other in  $T$ , in the same Point of the *Ecliptick*: In which Position *Venus* and the *Sun* are seen from the *Earth* likewise in *Conjunction*. After this, *Venus* circulating faster than the *Earth*, being come again to  $V$ , and having finished her Course, and by an angular Motion round the *Sun*, describing four Right Angles, will not have overtaken the *Earth*; who in the mean Time has proceeded farther in her proper Orbit. And therefore *Venus* must still move farther on to come in a Right Line between the *Sun* and the *Earth*. Let  $SLM$  be the next Right Line in which *Venus* is seen from the *Sun* together with the *Earth*, so that *Venus* may be in  $L$ , when the *Earth* is in  $M$ : Now before *Venus* can overtake the *Earth*, she must not only finish her own Circulation,





tion, or four Right Angles, but also so much angular Motion more, as the *Earth* has made in the mean time round the *Sun*. Now the angular Motion of *Venus* and the *Earth*, performed in the same Time, are reciprocally as the periodical Times of *Venus* and the *Earth*. And therefore, as the periodical Time of the *Earth* is to the periodical Time of *Venus*, so is the angular Motion of *Venus* (which is equal to four Right Angles, and more-over to the angular Motion the *Earth* makes from the Time of one *Conjunction* to the next) to the angular Motion of the *Earth*. And therefore by Division of Proportion, as the Difference between the periodical Times of the *Earth* and *Venus* is to the periodical Time of *Venus*, so are four Right Angles to a fourth Quantity; which shews the angular Motion of the *Earth*, from the Time of her *Conjunction* with *Venus*, to the Time of the next *Conjunction* of the same Kind. Now the periodical Time of the *Earth* is 365 Days and 6 Hours, or 8766 Hours. And the Period of *Venus* consists of 224 Days 16 Hours, or 5392 Hours, whose Difference is 3374 Hours. Say then, As 3374 is to 5392, so are four Right Angles, or 360 Degrees, to a fourth Number of Degrees, which is 575; which Motion is equal to a Circulation and a half, and besides to 35 Degrees; which angular Motion the *Earth* makes in the Space of one Year and 218 Days. And therefore, if *Venus* should be this Day in *Conjunction* with the *Sun*, in the inferior Part of her Orb, she will not come to the same *Conjunction* again, till after a Year and seven Months and twelve Days. And if one *Conjunction* be in the Beginning of *Aries*, the next will fall out when the *Sun* is in *Scorpio*. There is the same Distance of Time between any two other similar Positions of *Venus* and the *Sun*. For Example, between two superior *Conjunctions*, or between two such Situations of *Venus*, where she has a given Elongation from the *Sun* the same Way.

The Time  
between two  
Conjunctions  
of the  
same Kind.

THIS



Lecture  
XV.

Another  
Way of do-  
ing the same.

THIS *Problem* and another of the same Nature, about the *Conjunctions* of the *Sun* and *Moon*, are otherwise solved by the *Astronomers*; for they find out the Diurnal Motion of *Venus* seen from the *Sun*, and likewise the Diurnal Angular Motion of the *Earth*; and the Difference of these Motions is the relative Diurnal Motion of *Venus* from the *Earth*, or the Quantity by which *Venus* is seen to recede from the *Earth* every Day, by a *Spectator* in the *Sun*. Thus the middle Motion of the *Earth* is every Day about 59 Minutes and 8 Seconds: *Venus's* middle Motion in a Day, is 1 Degree 36 Minutes and 8 Seconds, whose Difference is 37 Minutes. Say therefore, As 37 Minutes is to 360 Degrees, or to 21600 Minutes, so is one Day to that Space of Time, wherein *Venus*, having left the *Earth*, has receded from her 360 Degrees; that is, to the Time in which she returns to the *Earth* again, which is the Time between two *Conjunctions* of the same Kind, which will be found to consist of 583 Days.

Plate XIII.  
Fig. 2.

BUT these *Conjunctions* are here computed according to the middle Motions of the *Planets*, supposing them to move always equably, or with the same Angular Velocity; and they are therefore called *mean Conjunctions*. But because *Venus* and the *Earth* are really carried in Elliptick Orbits, in which their Motions are constantly variable, sometimes going faster, and sometimes slower; it may be, that the true *Conjunctions* shall happen some few Days sooner or later than the Computation we have given; yet having the Time of the *mean Conjunction*, the true *Conjunction* is from thence to be computed after this Manner: Let A B C be the Ecliptick, in which A is the Point where the *Planets* are to be in *Conjunction* according to the mean Motion. For the Time of this *Conjunction*, compute by Astronomical Tables the true Places of the *Earth* and *Venus* in the Ecliptick; and suppose *Venus's* true Place in the Ecliptick to be D, and the *Earth* in T, by which we shall find the Distance of the *Earth* and *Venus* seen



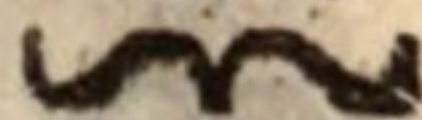
seen from the *Sun*: But we have, for that Time, the angular Motions of these two *Planets* for any given Space of Time; for Example, for six Hours; and the Difference of these two Motions will give the Access of *Venus* to the *Earth*, or her Recess from it in six Hours. Say then, As this Difference of Motions is to DT, so is six Hours to the Time between the mean *Conjunction* and the true; which Time, added to, or subtracted from, the Time of mean *Conjunction*, as *Venus* is to the *East* or *West* of the *Earth*, shews the Time of their true *Conjunction*.

IT is plain from the Inspection of the Figure, that though *Venus* does nearly always keep the same Distance from the *Sun*, yet she is continually changing her Distance from the *Earth*; and her Distance is greatest when she is seen in her superior *Conjunction* with the *Sun*; and it is the least when she is in her inferior *Conjunction*: And the Difference is so great, that it equals the whole Diameter of *Venus's* Orbit; so that the Distance of *Venus* from the *Earth*, when she is in her superior *Conjunction*, is to her Distance from the *Earth* in the inferior, as 1 to 6: And therefore *Venus* approaches the *Earth* six times nearer in the one Position, than in the other; and just so much are the apparent Diameters of *Venus* changed, as we observe them to be. But these greatest and least Distances are somewhat changeable, upon the Account of the Elliptical or Excentrick Orbits: For *Venus* is then most remote from the *Earth*, where the superior *Conjunction* happens when *Venus* and the *Earth* are both in their *Aphelions*. And the Distance of *Venus* and the *Earth* is the least of all, when the inferior *Conjunction* falls out when *Venus* is in her *Aphelion*, and the *Earth* in her *Perihelion*.

BECAUSE *Venus* is an opake Globe without any Light of her own, and only shines with the borrowed Light of the *Sun*, that Face of *Venus* will only appear bright, which is turned to-

M

wards

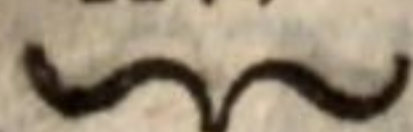
Lecture  
XV.

*Venus constantly changes her Distance from the Earth.*

*The Phases of Venus like those of the Moon.*



Lecture  
XV.



wards the *Sun*, while the Opposite remains in Darkness; and for want of Light, is altogether invisible. Wherefore, if the Situation of the *Earth* be such, that this dark Side of *Venus* be turned toward the *Earth*, *Venus* will become invisible, except by chance she appear like a black Spot in the Disk of the *Sun*: But if the whole illuminated Face of *Venus* be turned towards the *Earth*, as it is when she is near her superior *Conjunction*, then she appears like a full shining Orb; and according to the different Positions of the *Earth*, *Venus* and the *Sun*, *Venus* will have different Forms, and appear with different Faces and Figures, and will undergo the same Changes and Vicissitudes in her Appearances that the *Moon* does.

Plate XIII.  
Fig. 3.

LET ABCDEFGH be the Orbit of *Venus*, TL a Portion of the Orbit of the *Earth*, in which the *Earth* is at T, and let *Venus* be in A in her superior *Conjunction* with the *Sun*; it is manifest in this Situation of these two *Planets*, that the Face of *Venus*, which is illuminated by the *Sun*, is likewise turned towards the *Earth*; and then *Venus* will appear to us like a full, lucid Circle, as the *Moon* does at Full: But when she has gone from thence to the Position B, some Part of her obscure Hemisphere will be turned towards the *Earth*, and will lose something of her Fulness, and seem to us to be gibbose. When *Venus* comes to the Position C, but half her illuminated Side is turned towards the *Earth*, and then she is seen like a half Circle, as the *Moon* is when she enters in her first or last Quarter. But *Venus*, when she arrives at the Position D, has but a small Part of her illuminated Side turned towards the *Earth*: And because she is of a spherical Figure, which to us, because of its great Distance, appears like a Plane; the illuminated Part which we see, will appear to end in Points or Horns, whose Direction is always opposite to the *Sun*. But *Venus*, when she is in the Position E, that is, in her inferior *Conjunction* with the *Sun*, has her dark Side totally turned towards the *Earth*; and then she quite disappears, unless she



she happen to be in her *Node*, or near it; then she will appear like a black Spot to pass over the Body of the *Sun*, which delightful Spectacle was never seen by mortal Eyes but once; and it was our Countryman Mr. *Horrox*, who alone enjoyed that Pleasure. *Venus* will undergo the same *Phases* while she passes through F, G to H; viz. about F she is horned, in G a half Circle, in H gibbous, and in A again full.

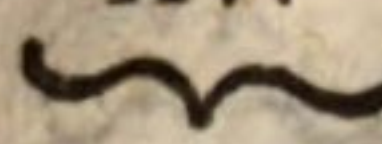
THESE Appearances of *Venus*, though they are not to be discerned by the naked Eye, yet they are distinctly and plainly to be perceived with a Telescope. Before the Invention of this noble Instrument, when *Copernicus* first revived the antient *Pythagorean System*, and proposed it to the learned in *Astronomy*, to whom he maintained, that the *Planets*, among which he reckoned the *Earth*, did move round the *Sun*, which was immoveable in the Center; it was objected to him, that if the Motions of the *Planets* were such as he supposed them to be, then *Venus* ought to undergo the same Changes and *Phases* as the *Moon* does. *Copernicus* answer'd, The Prophecy of Copernicus. that perhaps the *Astronomers* in After-ages would find, that *Venus* does really undergo all these Changes. This Prophecy of *Copernicus* was first fulfilled by that great *Italian* Philosopher *Galileus*, who directing his Telescope to *Venus*, observed her Appearances These Phases first observed by Galileus. to emulate the *Moon*, as *Copernicus* had foretold: And these Observations did surprizingly confirm the old System revived by *Copernicus*.

IF the Centers of the *Sun* at S, *Earth* at T, and one of the inferior *Planets* at O, be joined with Lines, they will form the Triangle TSO: And if through the Center of the *Planet* there pass two Planes, one perpendicular to the Line TO, and the other to the Line SO; the one will cut off the Hemisphere, which is turned towards the *Earth*; the other, that which is turned towards the *Sun*, and by him illuminated. And the exterior Angle of the Triangle TSO, which is at the *Planet*; that is, the Angle POS, will be equal to

Plate XIII.  
Fig. 4.



Lecture XV. the Angle  $m O q$ , which measures  $m q$  the Portion of the illuminated Semicircle that is turned towards

 the *Earth*. For the Angle  $S O r$  is a right Angle, and so is the Angle  $m O T$ , which are therefore equal; but the Angles  $r O P$  and  $p O q$  are likewise equal, being vertical to each other; and therefore, taking away Equals from Equals, there will remain the Angle  $S O P$ , equal to the Angle  $m O q$ ; which Angle is measured by the Arch  $m q$ . And therefore the Part of the illustrated Semicircle which is towards the *Earth*, and is to be seen from thence, does always measure the exterior Angle  $S O P$  of the Triangle  $S O T$ . Now this Arch, as seen from the *Earth*, is projected into its own versed Sine upon the Disk, as we shewed before in the *Moon*. And hence the Illumination of *Venus* seen from the *Earth*, is to her full and total Illumination, all other Things remaining the same, as the versed Sine of the exterior Angle at *Venus* is to the Diameter of the Circle.

The Quantity of Illustration.

ALTHOUGH *Venus* in *A* shines upon the *Earth* at *T* with a full Face or Orb, yet she does not appear there with her greatest Brightness and Lustre; for her Splendor is diminished on the Account of her greater Distance from the *Earth*; and it is lessened in a greater Proportion than the conspicuous Part of the illuminated Disk is increased. For the Lustre of *Venus* decreases in the duplicate Proportion of the Distance increased. But the visible illuminated Part of her Face increases only according to the versed Sine of the Angle  $S O P$ ; and therefore the greatest Brightness of *Venus* is not when she is in *A*, but rather when she is about *O*. For suppose *Venus* at *O* four times nearer the *Earth*, than when she is in *A*; in that Case every determined Part of the illuminated Disk will give sixteen times more Light, than the same Part does at *A*: But in *O* it may happen, that only a fourth Part of the illuminated Disk can be seen from the *Earth*; and therefore the Brightness of *Venus* is more increased by her Distance being diminished, than the same Brightness is lessened

on



on Account of a smaller Portion of her illuminated Disk being visible from the *Earth*. Lecture XV.

IF you desire to know in what Position *Venus* appears with the greatest Lustre, the great Geometer and Astronomer, Dr. Edmund Halley, my Colleague, has given us an elegant Solution of this Problem in the *Philosophical Transactions*, Numb. 349; wherein he has shewn, that *Venus* is brightest when she is about 40 Degrees removed from the *Sun*; and that then but only a fourth Part of her lucid Disk is to be seen from the *Earth*. And in this Situation *Venus* has been many times seen in the Day-time, even in full Sun-shine. This Beauty and Brightness of *Venus* is very admirable, who having no native Light of her own, and only enjoying the borrowed Light of the *Sun*, should yet break out into so great a Lustre, that the like is not to be observed in *Jupiter*, nor even in our *Moon*, when she is in the same Elongation from the *Sun*. 'Tis true, the *Moon's* Light is much greater, upon the Account of her apparent Magnitude, than that of *Venus*; yet it is but a dull, and, as it were, dead Light, which has nothing in it of that Vigour and Briskness that does always accompany the Beams of *Venus*. *Where the Illustration is greatest.*

IF the Plane of the Orbit of *Venus* coincided perfectly with the Plane of the Ecliptick, *Venus* would always seem to move in the Ecliptick, and no-where recede from it. But *Venus's* Orbit does not lie in the Plane of the Ecliptick, but is in a Plane which is inclined to it, in an Angle of 3 Degrees and 24 Minutes, and cuts the Plane of the Ecliptick, in a Line which passes through the *Sun's* Center, that is called the *Line of the Nodes*. And the two Points, where the Orbit of the Planet produced cuts the Ecliptick, are named the *Nodes*. And therefore *Venus* is never seen, either from the *Sun* or the *Earth*, in the Ecliptick, but when she is in the *Nodes*; in all the other Points of her Orbit, she is sometimes nearer to the Ecliptick, sometimes further from it; and seen from the *Sun*, she makes her greatest Excursion, when she is 90 Degrees distant from both the *Nodes*. *The Plane of Venus's Orbit does not lie in the Ecliptick.*



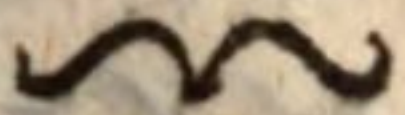
Lecture XV. LET TAB be a Circle in the Plane of the Ecliptick, L  $\propto$  V N the Orbit of *Venus*, cutting the Plane of the Ecliptick in the Line  $\propto$  N; we must conceive the one half of this Orbit of *Venus*  $\propto$  L N to be raised, or to stand above the Plane of the Ecliptick, and the other half  $\propto$  V N to fall below that Plane; and when *Venus* is in N or  $\propto$ , she is then in the Ecliptick: But when she arrives at P, she is seen to deviate from it; but in L, the Arch N L being a Quadrant seen from the *Sun*, she appears to recede the furthest from the Ecliptick; and this Point L is called the *Limit*, determining her greatest Excursion; for from thence departing, she again approaches the Ecliptick. If from the Place of *Venus*, as in P, we let fall on the Plane of the Ecliptick a Perpendicular P E, and draw S E, the Angle P S E will measure the Distance of *Venus* from the Ecliptick, which is called *Venus's Heliocentrick Latitude*, or such as it is seen from the *Sun*. Now this Latitude, having the Place of the *Planet* in its Orbit, is thus investigated: Let the Arch N E be a Portion of the Ecliptick, N P a Portion of the *Planet's* Orbit produced to the Heavens: Let P be the Place of *Venus*, N the *Node*; and let a Circle pass through the Place of the *Planet* perpendicular to the Ecliptick; the Arch P E of this Circle, intercepted between the *Planet* and the Ecliptick, is the Distance of the *Planet* from the Ecliptick, or the Measure of the Angle P S E. Now in the spherical Rectangular Triangle P N E, besides the Right Angle at E, we have the Side N P, the Distance of the *Planet* from the *Node*, also the Angle N the Inclination of the Plane of the Orbit to the Ecliptick; wherefore by *Trigonometry* we can find out P E, which is the *Heliocentrick Latitude* of the *Planet*. This *Heliocentrick Latitude*, when the *Planet* comes to the same Point of its Orbit, is always the same and unchangeable; But the *Geocentrick Latitude*, or the Distance of the *Planet* from the Ecliptick, as it is seen from the *Earth*, even though the *Planet* be in the same Point of her

Plate XIII.  
Fig. 5.

The Heliocentrick Latitude,

The Geocentrick Latitude,





her Orbit, is not constantly the same, but alters according to the Position of the *Earth*, in respect to the *Planet*. For let  $BTAt$  be the Orbit of the *Earth*,  $nPN$ , as before, the Orbit of the *Planet*, which suppose to be at  $P$ ; from which let fall on the Plane of the Ecliptick the Perpendicular  $PE$ : in whatever Part of her Orbit the *Earth* is, this Line  $PE$  will always subtend the Angle which measures the *Geocentrick Latitude* of the *Planet*. Suppose therefore the *Earth* at  $T$ , and *Venus* in  $P$ , where she comes nearest to the *Earth*; in which Position *Venus* is seen in her inferior *Conjunction* with the *Sun*, and her *Geocentrick Latitude* is measured by the Angle  $PT E$ . But if *Venus* should be in the same Situation  $P$ , and the *Earth* were at  $t$ , and from thence *Venus* were observed in her superior *Conjunction* with the *Sun*, where she is at her greatest Distance from us, her *Geocentrick Latitude* would be answerable to the Angle  $Pt E$ , which is much less than the Angle  $PT E$ ; because the Distance  $Pt$  is greater than  $PT$ . What we have here said of the Latitude of *Venus*, is likewise true of that of *Mercury*, and upon the same Account. Hence it is plain, that the inferior *Planets*, all other Things remaining the same, have a greater Latitude when they are near the *Earth*, than when they are further off. And it may happen, that the *Geocentrick Latitude* of *Venus* may be greater than her *Heliocentrick*, which will be when she is between the *Sun* and the *Earth*, and she is nearer to us than to the *Sun*. But *Mercury* keeping always at a greater Distance from the *Earth*, than he has from the *Sun*, his *Geocentrick Latitude* will constantly be less than his *Heliocentrick*, which, when at the biggest, is about 7 Degrees; for so much is the Inclination of his Orbit to the Plane of the Ecliptick.

SINCE none of the Orbits of the *Planets* lie in the Plane of the Ecliptick, but all of them cut it in a Line passing through the *Sun*, no *Planet* can be above twice in the Time of its Period in the Ecliptick, which is when they are in their



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XV.



The Zo-  
diack.

*Nodes*; at all other times every one of them will deviate, some more, some less, from the said Plane of the *Ecliptick*: But yet there are certain determinate Boundaries which they never transgress. And therefore, if we imagine in the Heavens a Zone, or broad Circle of 20 Degrees Breadth, that is, 10 Degrees on each Side of the *Ecliptick*, which lies exactly in the Middle of this Space or Zone; such a Space will constantly contain all the *Planets* in its Compass, and is called the *Zodiack*, from the Images of living Creatures, or the Constellations which fill that Part of the Heavens: The *Earth* keeping always, as it were, in the King's Highway, never turns out from its Course in the *Ecliptick*; but the *Moon*, and the other five Wanderers, will make Excursions from it, for several Degrees, sometimes to the *North-side*, and sometimes to the *South-side* of the *Ecliptick*; and yet they always keep within the Bounds of the *Zodiack*.

The Motion  
of Venus in  
the Zodiack.

Plate XIII.  
Fig. 7.

HITHERTO we have considered the Motion and *Phases* of *Venus*, as they have a Relation to the *Sun* and *Earth*: Let us next consider the Motions of *Venus* in the Heavens, as they are observed from the *Earth*, and the Way she takes in the *Zodiack*. For which Purpose let ABC be the Orbit of *Venus*, TGF the Orbit of the *Earth*, the Circle LMO the *Zodiack* among the *fixed Stars*: And, first, suppose the *Earth* in T, and *Venus* in A, near her superior *Conjunction* with the *Sun*; it is evident, that a *Spectator* on the *Earth* will see *Venus* at A, as if she were in the Point of the *Zodiack* L: If the *Earth* had no Motion while *Venus* moves from A to B in its Orbit, it would seem to describe the Portion of the *Zodiack* LM: But in the mean time the *Earth* also moves; and when *Venus* is in B, the *Earth* is come to the Point of its Orbit H; from whence the *Spectator* looking upon *Venus* at B, observes her in the *Zodiack* at N; so that she will seem to have run through the Space LMN in the *Zodiack*: And *Venus* will appear to have gone more *Eastward* than



than she would have done, had the *Earth* stood still without any Motion in its Orbit. But when *Venus* comes to C, the *Earth* has moved on to G; so that *Venus* is seen in the Line G O drawn from the *Earth*, which touches her Orbit; in which Position her apparent Motion in the *Zodiack* will be very nearly equal to the apparent Motion of the *Sun*. From thence let *Venus* move on from C to A, and in that Time the *Earth* will have come from G to K, and then *Venus* will be seen near her inferior *Conjunction* with the *Sun*; in which Position she will be observed in the *Zodiack*, as if she were at P: But before she was seen at O; and therefore she will here appear to have gone backwards in the *Zodiack* through the Arch O P, or to have moved from the *East* to the *West*, contrary to the Order of the Signs. And because in C she was observed to go *Eastwards* as fast as the *Sun* does; but in A she is seen to have a quick Motion backward: There must be some Place of her Orbit between C and A, where she appears to us neither to go forward nor backward, but to stand still, and continue in the same Place of the Heavens: In which Case she is said to be *Stationary*, or to stand still.

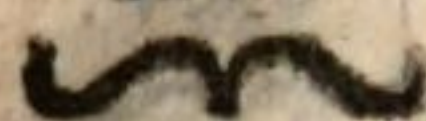
Venus Direct.

Venus Retrograde.

Venus Stationary.

LET *Venus* now arrive at E, and the *Earth* at the Point of its Orbit F: *Venus* will then be seen in the Point of the *Ecliptick* Q, and will appear to have moved further backwards in the *Ecliptick*, or towards the *West*. But when *Venus* is seen from the *Earth* in a Line which touches her Orbit, she will then seem to have a progressive Motion, equal to the apparent Motion of the *Sun* from *West* to *East*: And because before, her apparent Motion was backward, or from *East* to *West*, and now forward the contrary Way, from *West* to *East*, there must be some Place between the two contrary Motions, where she will neither appear to go backwards nor forward; but for some Time to stand still, and keep the same Position in the Heavens. While the *Earth* comes to D, and *Venus* arrives at C, she will appear in that Time to



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XV.

to have moved through the Arch QR of the *Zodiack*, and to have a quicker Motion towards the *East*. Hence *Venus*, when she is in her superior *Conjunction* with the *Sun*, is always seen to move directly according to the Order of the Signs; but when she is in her inferior *Conjunction*, and between the *Earth* and the *Sun*, then she is seen to have a backward Motion, and to be carried against the Order of the Signs, from *East* to *West*.

The Appear-  
ances of  
Mercury  
like those of  
Venus.

WHATEVER we have demonstrated concerning the Motions of *Venus*, is likewise true, and to be understood of the Motions of *Mercury*; but the *Conjunctions* of *Mercury* with the *Sun*, his Directions, Stations, and Retrogradations, are more frequent than in *Venus*; for *Mercury* circulating faster, and in a lesser Orbit than *Venus*, does oftner overtake the *Earth* than she. Hence it is plain, that the Motions of these two *Planets*, seen from the *Earth*, are very irregular and unequal, since they are sometimes seen to have a Motion forward; sometimes they appear immoveable or stationary; after this they change their Course, and move backwards; and after such a Regression, they again take up their Stations, and keep for some time the same Place in the *Zodiack*. Whereas a *Spectator* in the *Sun* will always observe these *Planets* to go forward with a Motion regulated after a certain Rate: For the apparent Inequality of these Motions, seen from the *Earth*, is such as exactly answers to a regular Motion round the *Sun*. And therefore it is manifest, that the *Sun*, and not the *Earth*, is the Center of these *Planets* Motion.

The Orbits of  
Mercury and  
Venus El-  
liptical.

WE shewed before, that the Orbit of the *Earth* was not a Circle, but an Ellipse; the same Thing is true of the Orbits of *Venus* and *Mercury*, and of all the other *Planets*, which are really Ellipses, and not Circles, that have one common *Focus* in which the *Sun* resides, about whom the *Planets* perform their Circulations with Motions, which though not perfectly equable, yet they are all regulated





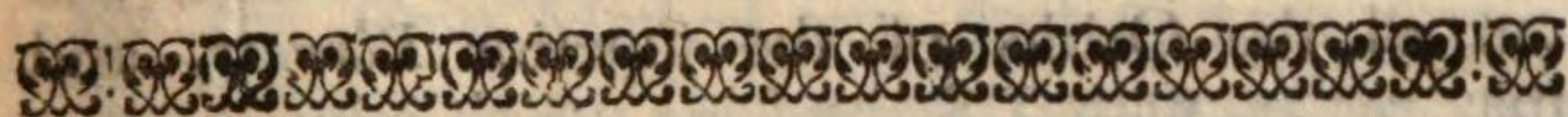


PLATE VII





gulated by a certain, unchangeable and constant Law, which none of them transgress; for every *Planet* moves in the *Perimeter* of his own Ellipse, so that the Line or Ray passing from its Center to the Center of the *Sun*, does always describe or sweep an Elliptick Space or *Area* proportional to the Time; or, which is the same Thing, in equal Time it sweeps an equal *Area*. Hence the *Planets* must move more slowly in their *Aphelia*, and quicker in their *Perihelia*: And these *Aphelia* are not like the *Apogeon* of the *Moon*; but they are either at Rest without Motion, or, if they have any, it is so slow, that it is not easily perceived in the Time of a Man's Age. And here it is to be observed, that of all the *Planets*, *Mercury* has the most Excentrick Orbit; for therein the Excentricity is to the mean Distance as 2051 to 10000.



## LECTURE XVI.

*Of the Motions of the three superior Planets, Mars, Jupiter and Saturn, and the Appearances arising from them.*



WE have now dwelt long enough on the Explications of the Motions of the two inferior *Planets*; let us next contemplate the Superiors. For which Purpose let A B C T be the Orbit of the *Earth*, and let Saturn, Jupiter and Mars, turn round the

*These superior Planets may have any Position or Aspect in respect of the Sun.*  
Plate XIV,  
Fig. 1.

*Sun* in different Orbits at their proper Distances, and perform their Circulations, each in its proper Period; and let P Q V be a Portion of the *Zodiack* in which these *Planets* are observed to perform their



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their Motions: *First*, It is plain that all these *Planets*, seen from the *Sun*, may be observed either in *Conjunction* with the *Earth*, or in *Opposition* to it. Thus *Saturn* may be in  $h$ , when the *Earth* is in  $M$ , in the Line which joins the Centers of the *Sun* and *Saturn*; in which Case the *Earth* and *Saturn* from the *Sun* are seen in *Conjunction*: But the *Earth* may likewise be in the same Right Line produced the contrary Way, as in  $B$ , where from the *Sun* these two *Planets* will be seen in *Opposition* to each other. But in this Situation, the *Sun* seen from the *Earth*, will appear to be in *Conjunction* with *Saturn*. *Secondly*, It is evident, that these *Planets*, seen from the *Earth*, may have any Aspect, or obtain any Position in respect to the *Sun*, and may have any desired Elongation from him; which cannot be in the inferior *Planets*, who are always confined to the Neighbourhood of the *Sun*. For from the *Earth*  $T$ , there may be drawn a Line  $TP$ , which will cut all the Orbits of the superior *Planets*, and may make, with  $TS$  the Line which joins the *Sun* and *Earth*, any Angle required, as  $STP$ . And therefore, when the *Earth* is in  $T$ , *Saturn* may be in  $F$ , whose Elongation from the *Sun* will then be the Angle  $STF$ . Moreover, when the *Earth* and any superior Planet are seen from the *Sun* in *Conjunction* together, that Planet, observed from the *Earth*, will appear in *Opposition* to the *Sun*; and an Inhabitant of our terraqueous Globe will see the *Sun* and it, in opposite Parts of the Heavens.

The Times  
between two  
Conjunctions,  
or two  
Oppositions,  
in the superior  
Planets.

LET now any superior Planet, as for Example, *Saturn*, be seen from the *Sun* in *Conjunction* with the *Earth*: After *Conjunction* the *Earth* having a quicker angular Motion than *Saturn*, an Inhabitant or Spectator in the *Sun* will see the *Earth* daily to recede more and more from *Saturn*. And because the *Earth*, according to its mean Motion, does every Day describe an Arch of the Ecliptick of 59 Minutes 8 Seconds, and *Saturn* moves only 2 Minutes in a Day, the *Earth* will appear from the *Sun*, to recede every Day from *Saturn* the Space of  
of



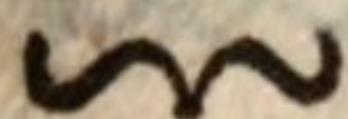
of an Arch of 57 Minutes 8 Seconds. If we say then, As 57 Minutes 8 Seconds is to 360 Degrees, or to 21600 Minutes, so is one Day to a fourth Quantity; we shall have the Number of Days in which the *Earth* will be again observed from the *Sun*, to be in *Conjunction* with *Saturn*, which is 378 Days. But when the *Earth* and *Saturn* are seen from the *Sun* in *Conjunction*, the *Sun* and *Saturn* from the *Earth* appear in *Opposition*. And therefore the Time between two *Oppositions* of the *Sun* and *Saturn*, immediately following one another, computed according to their middle Motions, is 378 Days, or 1 Year and 13 Days. And there is the same Time between two *Conjunctions* of *Saturn* and the *Sun* seen from the *Earth*, or between any two similar Aspects or Elongations from the *Sun*. And the Time between the *Opposition* and *Conjunction* of *Saturn* with the *Sun*, is the half of this Time, or 189 Days.

By the same Method we shall find, that the Time between two *Conjunctions* or *Oppositions* of *Jupiter* and the *Sun* consists of 398 Days, or a Year and 33 Days. But *Mars*, after an *Opposition*, does not again come into the same Situation, till after two Years and 50 Days.

WHEN the *Planets* are in *Opposition* to the *Sun*, they rise when the *Sun* sets, and set when he rises; and then, after their Departure from the *Opposition* to the *Sun*, they remain to the *Eastward* of the *Sun*; and after Sun-set they are to be seen in the Evening, till they come in *Conjunction* with him, when they set and rise together. Afterwards, as they recede from the *Sun*, they become more *Westerly* than he, and are then only to be seen in the Morning before the *Sun* is up; for in the Evening they set before the *Sun*, till they at last come to be opposite to the *Sun*, when again they rise at Sun-set.

As in the inferior *Planets*, so the superior have not their Orbits in the Plane of the Ecliptick; for the Planes of all their Orbits cut the Plane of the Ecliptick in Lines which pass through the *Sun*,  
The Planes of their Orbits are inclined to the Ecliptick,



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*Sun*, which are called, the *Lines of the Planets Nodes*: And the Points where these Lines meet with the *Ecliptick*, are called the *Nodes*. And therefore the superior *Planets* are never precisely in the *Ecliptick*, but when they are in the *Nodes*: In all the other Points of their Orbits they are further or nearer to the *Ecliptick*, according to their Distance from the *Nodes*; and their Distances are greatest, when they are at equal Distances from both *Nodes*; which Points are called the *Limits*, where the greatest *Heliocentrick* Latitudes, which measure the Inclinations of the Orbits to the *Ecliptick*, are as follow: *Saturn's* greatest *Heliocentrick* Latitude is 2 Degrees 30 Minutes; *Jupiter's* is 1 Degree 20 Minutes; and that of *Mars* is 1 Degree 52 Minutes.

The Heliocentrick and Geocentrick Latitudes.

Plate XIV.  
Fig. 2.

HAVING the Place of a *Planet* in its Orbit, or, which is the same Thing, its Distance from the *Node*, by the same Method we find out its *Heliocentrick* Latitude, as we did in the inferior *Planets Mercury* and *Venus*. But the *Geocentrick* Latitudes, or the Distances of the *Planets* from the *Ecliptick*, as they are seen from the *Earth*, depend much upon the Position and Distance of the *Earth*. For where the *Heliocentrick* Latitude continues the same, yet according to the various Positions the *Earth* may have, the visible Latitude of a *Planet* seen from thence, will be various. For let  $T \propto t$  be the Orbit of the *Earth*; and the Orbit of any superior *Planet*, as for Example, that of *Mars*, suppose to be  $\propto M$ , whose Plane is inclined to the *Ecliptick*, and cuts it in the Line of *Nodes*  $n N$ . Let *Mars* be in  $\propto$ , and the *Earth* in  $T$ , so as *Mars* may be observed in *Opposition* to the *Sun*; and from  $\propto$  let fall on the Plane of the *Ecliptick* the Perpendicular  $\propto E$ ; this Line will subtend the Angle which measures the *Geocentrick* Latitude. And therefore, when the *Earth* is in  $T$ , the visible Latitude is measured by the Angle  $\propto T E$ . But if the *Earth* was in  $t$ , so that *Mars* was seen in *Conjunction* with the *Sun*, its visible Latitude will be the Arch which measures the Angle



Angle  $\angle t E$ , which is much less than the Angle  $\angle T E$ , and is nearly less in the same Proportion as the Distance  $T \angle$  is less than the Distance  $t \angle$ . When the *Earth* is in  $T$ , the *Geocentrick* Latitude of *Mars* is greater than its *Heliocentrick*; but when it is in  $t$ , the *Heliocentrick* is greater than the *Geocentrick*; and according to the various Positions of *Mars* and the *Earth*, his visible Latitude will be changeable; so that all other Things being alike, the Latitude is greater, the nearer he comes to the *Opposition* of the *Sun*; and the less, as he approaches to a *Conjunction* with the same.

It is also evident, that none of the superior *Planets* can be seen from the *Earth* in the *Sun's* Disk, as the inferior *Mercury* and *Venus* are; but yet they may be all of them covered by the *Sun*, and lie behind him, when they come in *Conjunction* with him, and are near their *Nodes*.

SINCE the Faces of all the *Planets* which are turned towards the *Sun*, shine only with a reflected and borrowed Light; and because the *Earth*, seen from *Jupiter* or *Saturn*, is always to be observed near the *Sun's* Body; the Faces of these *Planets* which are turned towards the *Sun*, will also be towards the *Earth*; whence the Inhabitants of our Globe do always behold these *Planets* shining in full Orbs or Circles. But *Mars* having an Orbit which lies very near the *Earth*, its Face, which is towards the *Sun*, will not always be totally turned towards the *Earth*; but when in his Quadrature, or when there is about a fourth Part of the *Ecliptick* between the *Sun* and him, as suppose the *Earth* in  $M$  or  $B$ , and *Mars* in  $N$  or  $R$ , then some Part of the illuminated Face will be turned from the *Earth*; and therefore *Mars* will not appear in a complete Circle, but will be seen as deficient or gibbous; but when he comes to be in *Conjunction* or *Opposition*, he then re-assumes his round Figure, his illuminated Face being totally turned towards the *Earth*; and particularly, when, in *Opposition* to the *Sun*, he looks brightest and biggest.

*Jupiter and Saturn have always a round full Face.*

*Mars in his Quadrature, gibbous. Plate XIV. Fig. 1,*

FOR



Lecture XVI. FOR all the superior *Planets* appear much bigger when they are in *Opposition* to the *Sun*, than when

 they are in *Conjunction*, being much nearer to the *Earth* in the one Position than in the other; inso-  
 In Oppositi- much that the Difference of their Distances in  
 on the supe- these two Positions, is as great as the Diameter of  
 rior Planets that Orb in which the *Earth* goes round the *Sun* ;  
 are biggest. which Difference bears a considerable Proportion  
 to the Distance of *Mars* from the *Sun*, and greater  
 than it does to the Distances of the other *Planets* ;  
 and therefore will produce a great Difference in  
 his apparent Magnitude : For *Mars* is five times  
 nearer to us when he is in *Opposition*, than when  
 he is in *Conjunction* with the *Sun*. And therefore,  
 since the visible Disk and Lustre of a *Planet* in-  
 creases in a duplicate Porportion of that wherein  
 the Distance is diminished, *Mars* will appear 25  
 times bigger and brighter when he is in *Opposition*,  
 than when he is in *Conjunction* with the *Sun*.

The appa- BECAUSE *Jupiter* is five times further off the  
 rent Diamo- *Sun* than the *Earth* is, the apparent Diameter of  
 ter of the the *Sun* seen from *Jupiter* will be five times less  
 Sun seen than it is seen from the *Earth*, and will be no big-  
 from Jupiter ger than 6 Minutes, which to us is 30 Minutes.  
 and Saturn. And the Disk of the *Sun* will appear 25 times  
 less to the Inhabitants of *Jupiter*, than it does to  
 us, who will likewise receive but the 25th Part of  
 the Light and Heat from him that we enjoy. But  
*Saturn* being ten times further from the *Sun* than  
 we, the apparent Diameter of the *Sun* seen from  
 him, will be no bigger than 3 Minutes, and will  
 be but little more than twice the Diameter of *Ve-*  
*nus*, when she approaches nearest to the *Earth* :  
 And therefore the Disk of the *Sun*, as it would  
 appear to a *Saturnian Astronomer*, will be a Hun-

Their De- dred times less than we see it ; and both its  
 grees of Heat Light and Heat are there diminished in the same  
 compared Proportion ; and therefore the warmest Regions  
 with our Heat, which in *Saturn*, even under his *Æquator*, are much  
 we receive from the *Sun*. colder than our Frigid Zones.

ALL











ALL the superior *Planets* observed from the *Sun*, Lecture  
 will appear to move regularly the same Way, and XVI.  
 to proceed in their Orbits according to the same Law; which is the equable Description or sweeping of Elliptick *Area's* round the *Sun*; by which means their angular Motions round the *Sun* will appear somewhat unequal: For in their *Aphelia*, they proceed more slowly; in coming to their *Perihelia*, they accelerate their Motions. But these *Planets*, observed from the *Earth*, have very different Appearances, and irregular Motions in the *Zodiack*. Sometimes they seem to move forward from *West* to *East*, according to their real Motions; then they by Degrees slacken their Pace, till at last they lose all their Motion, and seem to stand still. After some small Time they are again set a moving, but seem to take a contrary Course to what they had before; and go backwards directly in Opposition to their real and true Motions. And thus having for some Way gone backward, or from *East* to *West*, they come again to be immoveable and stationary. These great Changes of their Courses and Motions are not real in the *Planets*, but are occasioned by the Motion and Position of the *Earth*, from whence the *Astronomer* observes them.

LET P Q O be a Portion of the *Zodiack*, Plate XV.  
 ABCD the Orbit of the *Earth*, EMGHZ Fig. 1.  
 the Orbit of a superior *Planet*: For Example, of *Saturn*; and suppose the *Earth* in A, and *Saturn* in E; in which Position he will appear in the *Zodiack* at the Point O. If *Saturn* remained there without any Motion of his own, when the *Earth* comes to B, he would be seen in the Point of the *Zodiack* L, and would appear to have described the Arch of the *Zodiack* O L, and to have moved according to the Order of the Signs, from *West* to *East*. But because in the mean time, while the *Earth* is passing from A to B, *Saturn* does likewise move in his own Orbit from E to M, where he is seen in *Conjunction* with the *Sun*, he will appear to have described the Arch of the *Zodiack* O Q,  
 N which



Lecture which is greater than the Arch OL ; whence the  
 XVI. superior *Planets*, when they are in *Conjunction*

When the  
 superior  
 Planets are  
 direct and  
 swift.

with the *Sun*, appear to have a Motion forward much quicker than at other Times, and that for a twofold Cause ; which is, because they really have a Motion forward from *West* to *East* ; and likewise, because the *Earth*, in the opposite Part of the Heavens, is carried the same Way round the same Center. And therefore these *Planets*, when they are at their greatest Distance from us, and in *Conjunction* with the *Sun*, appear to have a quicker Motion than usual to the *East*, according to the Order of the Signs : In which Position a *Planet* is said to be direct, or to have a direct Motion. When the *Earth* comes to C, while *Saturn* describes the Arch MG, he will then be observed in the *Zodiack* at R. But the *Earth* being advanced to K, and *Saturn* to H, so as the Line KH joining the *Earth* and *Saturn*, continue for some time parallel to itself, or very nearly so ; then our *Astronomers* will observe *Saturn* all that while in the same Point of the *Zodiack* at P, and with the same *fixed Stars*, he then appearing Stationary. But the *Earth* being come to D, and *Saturn* coming into *Opposition* to the *Sun* in X, he will appear in the *Zodiack* at V, and will seem to have gone backwards through the Arch P.V. And therefore the superior *Planets*, when they are in *Opposition* to the *Sun*, are always retrograde, or appear to have a backward Motion from *East* to *West*, which is contrary to the Order of the Signs. But when the *Earth* comes again to A, and *Saturn* remaining near to Z, again that *Planet* will seem there to occupy his Station, and to remain without Motion. At last, after the *Earth* has left that Situation, *Saturn* will appear to begin again to move forward.

When Sta-  
 tionary.

WHAT we have here shewed concerning *Saturn*, is likewise to be understood of *Jupiter* and *Mars*, who are likewise observed to have all these Variations and Changes in their Motions, as some-  
 times



times to move quickly forwards, then to stand still, and after that to fall backward; then again they become Stationary; and in a short time after they go forward with a direct Motion. But the Regressions or backward Motions of *Saturn*, are more frequent than those of *Jupiter*; because the *Earth* more frequently overtakes *Saturn* whose Motion is slower than *Jupiter's*, who is not a little quicker in his Motion. And for the same Reason *Jupiter's* Regressions do oftener happen than those of *Mars*; because *Mars* moving faster, describes a greater Space in the *Zodiack*; so that there is more Time necessary for him to come in *Opposition* to the *Sun*, than what *Jupiter* needs for that Purpose.

When Retrograde.

LET AC be a Portion of the *Earth's* Orbit, which is touched by the right Line AN, in which we will suppose the superior *Planets* to be seen from the *Earth*, viz. *Mars* in ♂, *Jupiter* ♃, and *Saturn* in ♄; and let K L M N be a Portion of the *Zodiack*. Then the Place of *Mars* seen from the *Sun* is K, which is called his true or heliocentrick Place. But an *Astronomer* on the *Earth* will observe him at the Point N, which is called his apparent or geocentrick Place; so likewise *Jupiter*, seen from the *Sun*, appears in L, which is his true Place; but from the *Earth* his apparent Place is N. After the same Manner the true Place of *Saturn* seen from the *Sun*, the Center of his Motion, is M; but his Place in the *Zodiack*, that is visible from the *Earth*, is N. The Arches KN, LN, MN, the Differences between the true and apparent Places of the superior *Planets*, are called the *Parallaxes* of the annual Orb in these *Planets*. Through the *Sun* S draw SO parallel to AN, and by the 29th of the 1st of *Euclid*, the Angles A ♂ S, A ♃ S, A ♄ S, will be respectively equal to the Angles KSO, LSO and MSO. But the Angle ANS is equal to the Angle NSO, whose Measure is the Arch NO, which will therefore be the Measure of the Angle ANS, which is the Angle under which the

The Parallax of the annual Orb.

Plate XV.  
Fig. 2.



Lecture XVI. Semidiameter AS of the *Earth's* Orbit is seen from the starry Heavens. But this Semidiameter is nothing in respect of the great Distance of the Heavens or Stars; for from thence it would appear under no sensible Angle, and look like a Point. And therefore in the Heavens the Angle NSO, or the Arch NO vanisheth, and the Points N and O coincide; and the Arches KO, LO, MO, are of the same Bigness with the Arches KN, LN, and MN, which are therefore the Measures of the Angles A  $\angle$  S, A  $\angle$  S, A  $\angle$  S. But these Angles are as the apparent Semidiameters of the Orbit of the *Earth* seen from the respective *Planet*: And therefore in each of the superior *Planets* the *Parallax* of the annual Orbit is equal to the Angle under which the Semidiameter of the *Earth's* Orbit is seen from that *Planet*; and the nearer any of them is to the *Earth* or *Sun*, so much the bigger is that Angle. And therefore this *Parallax* in *Mars* is greater than in *Jupiter*, and again in *Jupiter* greater than it is in *Saturn*. But in the *fixed Stars* there can be no *Parallax* of the annual Orb observed, it being so very small.

The Retro-  
gressions of  
Mars great-  
er than those  
of Jupiter;  
and Jupi-  
ter's greater  
than Sa-  
turn's.

IT is also evident from hence, that the Retrogressions of *Mars* are greater than those of *Jupiter*, though they do not happen so often; so likewise *Jupiter* has his Retrogressions greater than those of *Saturn*; and that upon a double Account: First, because *Mars* is nearer to the *Earth* than *Jupiter*, and *Jupiter* nearer than *Saturn*; and likewise because they move faster.

HAVING the *Parallax* of the annual Orb in any *Planet*, we can from thence easily find his Distance from the *Sun*, in respect of the *Earth's* Distance from him. For in *Mars*, because the Angle A  $\angle$  S is given, being measured by the *Parallax* of the annual Orb, and the Angle  $\angle$  AS is found by Observation, being the visible Elongation of *Mars* from the *Sun*: If we make the Proportion, as the *Sine* of the annual *Parallax* is to the *Sine* of the Elongation, so let SA the Distance of the *Earth* from the *Sun* be



be to a Fourth, which will be  $\frac{3}{4}$  S, the Distance of *Mars* from the *Sun*. This annual *Parallax*, by which the *Planets* seem sometimes to move faster, sometimes slower, in the Heavens, sometimes to go *Eastward*, and sometimes *Westward*, produces in their Motions an Inequality; which, by the *Astronomers*, is called their *second* or *optical* Inequality, to distinguish it from their first Inequality, which the *Planets* really have, by which they move in their Orbits with Motions that are not always the same. In the *Oppositions* or *Conjunctions* of these *Planets* with the *Sun*, this second Inequality or *Parallax* vanishes; and their *Geocentrick* Places and the *Heliocentrick* coincide; or a *Spectator* in the *Sun*, and another in the *Earth*, would observe the *Planet* in the same Point of the Heavens.

THE Angles  $A \frac{3}{4} S$ ,  $A \frac{1}{2} S$ ,  $A \frac{1}{4} S$ , are nearly the greatest Elongations of the *Earth* from the *Sun*, if she were observed from the respective *Planets*, when the Line  $N \frac{3}{4} A$  touches the *Earth's* Orb in  $A$ . In *Mars* the Angle  $A \frac{3}{4} S$  is about 42 Degrees; and therefore the *Earth*, seen from *Mars*, never goes so far from the *Sun* as we see *Venus* does. In *Jupiter* the greatest Elongation of the *Earth* from the *Sun* will be observed to be but 11 Degrees, and therefore is not so much as half the Distance we observe *Mercury* to depart from the *Sun*. In *Saturn*, the Angle  $A \frac{1}{2} S$ , or the greatest Elongation of the *Earth* from the *Sun* that can be seen from that *Planet*, is but 6 Degrees, and not much above a fourth Part of the greatest Elongation we observe in *Mercury*. And since *Mercury* is but seldom seen by us, a Sight of the *Earth* from *Saturn* may be a rare and unusual Spectacle: Perhaps the *Saturnian Astronomers* have not yet discovered, that there is such a Body as our *Earth* in the Universe.

EACH of the two outmost of the *Planets* have a good Company of Attendants; for *Jupiter* keeps no fewer than four constantly by him, and *Saturn* five in his Retinue, which is a Sight no less wonderful than delightful. These *Satellites*, like our *Moon*, do



Lecture always accompany their primary *Planets* in their Circuits round the *Sun*; and in the mean time they perform their proper Circulations about their Primaries; and therefore they will have the same *Phases* and Figures that our *Moon* shews us: When they are in *Opposition* to the *Sun*, they appear to *Saturn* and *Jupiter* bright and full; from thence receding, they assume a gibbous Shape. When they come to a *Quadrantile Aspect*, they look like Half-Moons; before the *Conjunction* they shew themselves in horned Figures; and when they come to be joined in the same Line with the *Sun*, they totally disappear.

THESE *Satellites*, seen from the *Earth*, though they go, at the furthest, but a little Way from their Primaries, yet sometimes they approach them nearer, and sometimes remove a little further from them.

Plate XV. Let A B T be the Orbit of the *Earth*, in the Middle of which the *Sun* resides. Let E F be a Portion of the Orb of *Jupiter*; in which let *Jupiter* be in  $\Psi$ , who keeps in the Middle of the Orbits of his four Attendants. These *Satellites* or *Moons*, when they describe the inferior Parts of their Orbits L M N, seen from the *Earth* or *Sun*, will appear to have a Motion *Westward*; but while they are moving through the superior Portions G H K, we observe them to move *Eastward*, according to their true Motions. Now when their visible Motion is *Eastward*, they are twice hid from us; once in O behind the Body of *Jupiter*, that is, in the right Line which joins the Centers of the *Earth* and *Jupiter*; and again they vanish and become invisible, when they fall into the Shadow of *Jupiter*, or are in the right Line which joins the Centers of the *Sun* and *Jupiter*; and then they suffer Eclipses, which is always when they are at their Full, as seen from *Jupiter*: These Eclipses happening in the same Manner as they do to our *Moon*, by the Interposition of the *Earth* between the *Sun* and it.

WHEN *Jupiter* is to the *East* of the *Sun*, and is seen in the Evening after Sun-setting; that is, when the *Earth* is in A, they are first hid behind *Jupiter*,



*Jupiter*, because of their visible *Conjunction* with *Jupiter*, before they fall into his Shadow; and their second disappearing is in the Eclipse, upon their entering the Shadow. But when *Jupiter* is more *Westerly* than the *Sun*, as he appears after *Conjunction*, when he is only seen in the Morning; that is, when the *Earth* is about B, then they fall into *Jupiter's* Shadow at V, and are eclipsed, before they are hid behind his Body in P. But when these *Moons* have a retrograde Motion, that is, when they are seen to go *Westward*, and describe the inferior Parts of their Orbits, then they only once disappear in Q, when they cannot be distinguished from the Body of *Jupiter*: But when the *Satellites*, seen from the *Sun*, are in their inferior *Conjunction* with *Jupiter*, or as seen from *Jupiter*, they are in *Conjunction* with the *Sun*, their Shadows will fall upon *Jupiter*, and some Part of the Disk of *Jupiter* will be in an Eclipse, and a *Spectator* within the Shadow would observe a total Eclipse of the *Sun*. We have already given the Distances and Periods of all the *Jovial* and *Saturnian Moons*, at the End of our third Lecture.

By the Motions and Eclipses of these *Moons*, the *Parallax* of the annual Orb in *Jupiter*, and his Distance from the *Sun*, may be easily known. For, let P O R be the Orbit of any *Satellit*; for Example the outermost; and suppose the *Earth* in the Point of its Orbit A, the Time must be observed when the *Satellit* lies hid behind *Jupiter's* Body in O: For which Purpose the Moment of Time must be carefully mark'd when he first disappears, and then also the Moment he becomes again visible; the middle Moment between these two, is the Time when the *Satellit* is in O, or in the Line which passes through the Centers of the *Earth* and *Jupiter*. After the same Manner observe when the *Satellit* is in the middle of an Eclipse, or in the middle of *Jupiter's* Shadow, that is, when it is in V; by this means we shall have the Time it takes to describe the Arch O V. And because his Motion about *Jupiter* is equable,

*The Parallax of the annual Orb, and the Distance of Jupiter from the Sun, determined by the Eclipses.*



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and his periodical Time known, we can from thence find out the Arch  $OV$ ; for this *Planet* revolves about *Jupiter* in 402 Hours. Let us suppose the Time he takes to move from  $O$  to  $V$  be 12 Hours; say, As 402 Hours are to 12 Hours, so are 360 Degrees to a fourth Quantity, which will be found to be 10 Degrees 44 Minutes. And therefore the Arch  $OV$  is 10 Degrees 44 Minutes. But this Arch  $OV$  is the Measure of the Angle  $O\psi V$ , or of the Angle which is equal to it  $A\psi S$ ; and the Arch which measures this Angle is the *Parallax* of the annual Orb, which therefore is known. In the Triangle therefore  $A\psi S$  we have the Angle at  $\psi$ , and also the Angle at  $A$  the Elongation of *Jupiter* from the *Sun*, which may be had either by a Calculation from Astronomical Tables, or by Observation. Besides, we have the Side  $AS$ , the Distance of the *Earth* from the *Sun*, which we assume to consist of 100000 Parts. Since therefore in this Triangle we have all the Angles and one Side, by *Trigonometry* we shall find the other Sides, and particularly  $S\psi$  the Distance of *Jupiter* from the *Sun*; so likewise we may find  $A\psi$  the Distance of *Jupiter* from the *Earth*, which is always variable. But for the nice Determinations of these Distances, it may be needful to have several, and those very accurate Observations, made by the Skilful, and taken by the Help of the best Telescopes.

Whether  
Light be  
propagated  
in an In-  
stant, or in  
Time?

By the Eclipses of *Jupiter's Moons* we are able to give a Solution of a Problem, which is the most noble and curious in natural Philosophy, which cannot but raise our Wonder and Amazement; that is, Whether Light be propagated to us in an Instant; or if its Motion be successive, and if it takes some Time to arrive from the *Sun*, or any distant Object, to us? Now these Eclipses do shew us, that there is no instantaneous Motion in Light, though it comes from the Heavens to us with a prodigious quick Motion, and incredible Celerity.

FOR



FOR if the Motion of Light were in an Instant, when the *Earth* is at T, at his greatest Distance from *Jupiter*, an *Astronomer* here would observe an Eclipse of a *Satellit* at the same Moment of Time he would do, were the *Earth* at X at her nearest Distance to *Jupiter*: For, according to this *Hypothesis*, Light is propagated in the same Distance through all Spaces indefinitely, whether near, or never so much remote. But if Light takes up any Time for its Propagation thro' Space, it will sooner pass through a shorter Space than a greater. And therefore an Observator at X, being nearer to *Jupiter* than one at T, by the Distance XT, which is almost equal to the Diameter of the *Earth's* Orbit, will sooner observe the Eclipse of a *Satellit*, than a *Spectator* can do at T. And therefore from the Difference of those Times, which is proportional to XT the Difference of Distances, we can collect the Velocity of Light; and so this Matter is in Reality. For whenever the *Earth* is at its nearest Distance from *Jupiter*, the Eclipses are found to happen sooner than they do when they are observed from T at a greater Distance, where they fall out sensibly later than they ought to be, according to our Astronomical Computations. These quicker and slower Returns of Eclipses having been observed for many Years by Mr. *Romer* with much Care and Diligence, upon them he founded this Argument for demonstrating the successive Propagation of Light; and by them be proved, That Light, like all other Bodies in Motion, had a determined Degree of Velocity, and took a determined Time to move through a given Space. To which Opinion the most Part of the *Astronomers* and *Philosophers* do now give their Assent.

THE Particles therefore of Light, though their Minuteness be indefinite, and not easily to be imagined, yet they have a progressive Rectilinear Motion, and are not diffused as by the Waves of any *Medium* or Fluid. *Romer* determines the Velocity of Light to be such, that it reaches us here from the

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This Question determined by the Observation of the Eclipses of Jupiter's Moons.

Sun



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The Longi-  
tude of Pla-  
ces determi-  
ned by the  
Observations  
of those Ec-  
lipses.

*Sun* in the Space of 11 Minutes: But that Distance does not seem to be less than 50000000 Miles; which Space Light passes thro' in so small a Time, that so prodigious a Velocity cannot easily be conceived by us, which so much exceeds the Velocity of the swiftest Bodies we know. For though the *Earth* has a very quick Motion round the *Sun*, yet its Velocity, compared with the Velocity of Light, is no more than that of a Snail, in Comparison of the Swiftness of the *Earth*.

FROM the Eclipses of *Jupiter's Moons*, we have likewise this Advantage, that when they are observed in different Places of the *Earth*, the Longitude of Places are by such Observations determined. But that this Method of finding the Longitude may be more easily understood, we must first lay down some few Principles.

IF through the Poles of the *Earth* and any Place, there be drawn a great Circle upon its Surface, this Circle, by the Rotation of the *Earth*, will be turned round the *Earth's Axis*: And when the Plane of this Circle produced passes thro' the Body of the *Sun*, all the Inhabitants which live under this Circle will then observe the *Sun* to come into their Meridian, and they will have Mid-day; from whence this Circle has the Name of a Meridian, from the *Latin Word Meridies*, which signifies Mid-day. Now if we imagine another Meridian placed more *Westwardly*, which, with the former, makes an Angle of 15 Degrees, the Plane of this Meridian will pass through the *Sun* one Hour later than the former did; and therefore, when the Inhabitants under this Meridian reckon Mid-day, the Inhabitants under the first will reckon one Hour after Mid-day. If there be a Meridian which makes an Angle of 30 Degrees with the first we mentioned; then, when they that live under this Meridian have Mid-day, those that live under the first, will reckon two of the Clock after Mid-day; and so for every 15 Degrees of the *Æquator* which lies between the two Meridians, so many Hours more do they reckon, who



who live under the more *Eastern* Meridian, than they who live under the *Western*. And after the same Manner for every Degree of the *Æquator* between Meridians, the *Eastern* People are four Minutes sooner in their Reckoning than the *Western*; and for every 15 Minutes of a Degree, they reckon one Minute in Time. As for Example, If the Arch of the *Æquator* between the two Meridians consists of 85 Degrees; dividing 85 by 15, the Quotient  $5\frac{2}{3}$  shews, that under the more *Easterly* Meridian they reckon the fifth Hour and 40 Minutes, when they under the *Western* Meridian have Mid-day; and when the *Eastern* People have Mid-day, those to the *West* will reckon their Time to be the sixth Hour and 20 Minutes in the Morning; and the Difference between the Hours which are reckon'd under these two Meridians, will always be  $5\frac{2}{3}$ , if the Arch of the *Æquator* intercepted between them be 85 Degrees.

ON the contrary, having the Difference of the Hours which are reckon'd under two different Meridians for the same Moment of Time, we shall by this Difference find the Arch of the *Æquator* intercepted between them; which Arch is called the *Difference of Longitude* of the Places under those Meridians, when the Longitudes are computed from one fixed and settled Meridian, which is called the *first Meridian*: And this Arch is found by multiplying the Difference of the Hours by 15, and the Product shews the Degrees. So likewise, if the Minutes of Time be multiplied by 15, and the Product, if it exceed 60, be divided by 60, the Quotient and Residue will give the Degrees and Minutes that are further to be added to the former, and which make up the Difference of Longitude of Places. For Example, Suppose the Difference of the Hours to be 7 and 22 Minutes; 7 multiplied by 15 is 105, and 22 by 15 is 330 Minutes; which divided by 60, gives 5 Degrees 30 Minutes: And therefore the whole Difference of Longitude is 110 Degrees 30 Minutes. These Things being noted,

IF



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IF in two different Places the Beginning of an Eclipse of any of *Jupiter's Moons* be observed, and the Times marked when this Beginning happened; according to the Times of the respective Places, the Difference of Hours, converted into Degrees and Minutes of the *Æquator*, will shew the Difference of Longitude of those Places.

IF we had *Ephemerides* of the Motions and Eclipses of *Jupiter's Moons*, accurately computed for any Meridian; instead of an Observation in another Place, we might consult the *Ephemerides*, which tell when the Eclipse is to be observed in that Place; and we might take from them the Hours and Minutes when the Eclipse happens in that Place; and this Time, compared with the Time the Eclipse is observed in any other Place, will give the Difference of Times in those two Places: And from thence we can find out the Difference of their Longitudes, as before. The Longitude of Places may likewise be found by Observations of Eclipses of the *Moon*, or the *Appulses* of the *Moon* to the *fixed Stars*, observed from several Places: But these are Appearances that are more seldom to be observed, than are the Eclipses of the *Satellites* of *Jupiter*.

Upon Land  
the Eclipses  
are easily  
observed, and  
the Longi-  
tudes found,  
but not at  
Sea.

UPON Land and firm Ground the Eclipses are easily observed; and if they could be as easily observed at Sea, the Art of Navigation would be brought almost to Perfection, and liable to no Errors in Computation; but at Sea the Motion and Tossings of the Ship render all Observations of such Eclipses impracticable. And therefore, if any could find a Method for determining the Longitude of a Ship at Sea at any Time, he would then oblige the Seamen with a Discovery, by them more desired than any thing else in Navigation; and which would be so useful to the Publick, that the Parliament hath thought fit to allow a large Reward of 20000 Pounds to the Discoverer. Upon which many, tempted by so great a Reward, have spent much Labour and Thought, to make the Discovery, but to no Purpose: For  
no





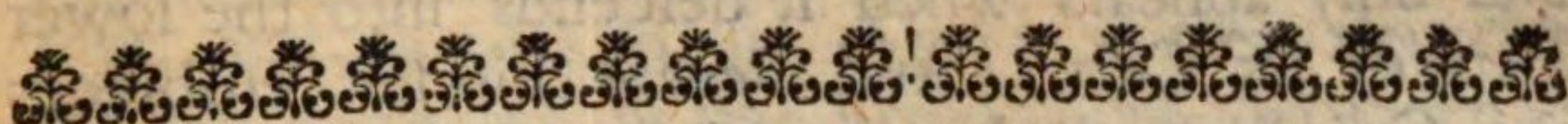






no Man has hitherto been able to lay hold on the Reward, though they have proposed many different Methods and Ways of attaining it. Many being much in love with their own Inventions, imagining that they had certainly found it, have demanded the Reward promised to the Discoverer; but yet most of these Men have been so ignorant, that they have scarce known what it is to find the Longitude.

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## LECTURE XVII.

## Of COMETS.



BESIDES the ordinary *Planets*, which are Comets are always in our Neighbourhood, and a Sort of Planets. within our View, there are another Sort of *Planets*, which may be called *Temporary*; which are conspicuous only for a Season, after which they again withdraw, and are no longer visible. The ancient Philosophers allowed them a Place in the heavenly Regions, and ranked them in Stations far above the *Moon*. For The Philosophers Opinion of Comets. *Aristotle*, *Seneca*, *Plutarch* and others testify, That the *Pythagoreans*, and the whole *Italian* Sect, maintained that a Comet was a Kind of *Planet* or *wandering Star*, which appeared again after a long Interval of Time. *Hippocrates Chius* was of the same Opinion, as *Aristotle* informs us: The same was the Opinion of *Democritus*, as we are told by *Seneca* in his *Natural Questions*, Book VII. Chap. 3. For, says he, “*Democritus*, the most curious and “subtle of all the Ancients, suspected, that there “were many more *Stars* which moved, under- “standing by them the *Comets*; but he neither “established their Number or their Names, the “Courses



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“ Courses of the five *Planets* not having as yet been  
 “ discovered.” Again, *Seneca* assures us, That *Apol-*  
 “ *lonius Myndius*, one of the most skilful Philosophers  
 in the Search of Natural Causes, did assert, That  
 the *Chaldeans* reckon’d Comets among the other  
*wandering Stars*, and that they knew their Courses.  
*Apollonius* himself maintained, That a Comet was a  
*Star* of its own Kind, as the *Sun* and *Moon* are,  
 but that its Course was not yet known: That by  
 its Motions it mounts very high in the Heavens,  
 and only appears when it descends into the lower  
 Part of its Orb. And *Seneca* himself embraces  
 this Opinion: “ I cannot believe, says he, that a  
 “ Comet is a Fire suddenly kindled, but that it  
 “ ought to be ranked among the eternal Works of  
 “ Nature. A Comet has its proper Place, and is  
 “ not easily moved from thence; it goes its Course,  
 “ and is not extinguished, but runs off from us.  
 “ But you will say, if it were a *wandering Star*, it  
 “ would keep in the Zodiack: But who can set  
 “ one Boundary to all the *Stars*? Who can re-  
 “ strain the Works of the Divinity to a narrow  
 “ Compass? For each of those Bodies which you  
 “ imagine to be the only that have Motion, have  
 “ very different Circles; why therefore may there  
 “ not be some that have peculiar Ways of their  
 “ own, wherein they recede far from the rest?  
 “ But that their Courses may be known, it is ne-  
 “ cessary to have a Collection of all the ancient  
 “ Observations about Comets; for their Appear-  
 “ ances are so rare, that their Orbits are not yet  
 “ determined; nor can we as yet find if they have  
 “ their Periods, and if they return again in a cer-  
 “ tain Order.” At last he thus prophesies: “ The  
 “ Time will come wherein these Things, which  
 “ are now hid from us, will be discovered; which  
 “ Observation, and the Diligence of After-Ages  
 “ will find out; for it is not one Age that is suf-  
 “ ficient for so great Matters. The Time will  
 “ be when Posterity will wonder that we were  
 “ ignorant of Things so plain: One will arise  
 “ who will demonstrate in what Regions of Space  
 “ the



“ the Comets wander, why they recede so far  
 “ from the other *Planets*, how great, and what  
 “ sort of Bodies they are.”

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BUT for all this, the whole Sect of *Peripateticks*, fearing that Generations and Corruptions should be introduced into the Heavens by placing the Comets in them, thrust all the Comets down into the sublunary Regions, and would maintain, that they were nothing but a kind of Meteors. But the *Phænomena*, or the Manner these Comets appear in, will not suffer them to have a Place so low, and so near to us. For it is clear that they are not generated in our Atmosphere, because they are certainly far higher than it reaches: For Comets are to be seen at the same Time from different Parts of the *Earth*, which are at great Distances from one another; which cannot happen to any Body that resides within our Atmosphere, which is not extended upwards above fifty Miles.

*The Peripateticks supposed Comets to be Meteors generated in the Air.*

BUT that Comets are not only above the Air, but also beyond the *Moon*, is plain; because Comets, seen from different Places, are observed to be at the same Distance from a *fixed Star* which is near them. As for Example, the Comet which *Tycho Brahe* observed at *Uraniburg*, was likewise seen by *Hagecius*, at *Prague* in *Bohemia*, at the same Time, which two Places differ 6 Degrees in Latitude, and are nearly under the same Meridian; and both measured the Distance of this Comet from the *Star* we call the *Vultur*; that is, how much it was below it towards the Horizon; for both the *Vultur* and it were in the same Vertical Circle, and both Observators found their Distance the same, and consequently they both viewed the Comet in the same Point of the Heavens; which could not be, unless it had been higher than the *Moon*.

*Comets are higher than the Moon.*

LET the Circle *ABG* represent the *Earth*, in which let *Uraniburg* be in *A*, and *Prague* at *B*: Let *D* be the Place of the Comet: Let *FCE* be the Firmament of the *fixed Stars*, in which let the *Star F* be the *Vultur*; the Place of the Comet

Plate XVI.  
 Fig. 1.  
*A Demonstration that Comets are higher than the Moon.*

seen



Lecture XVII.  seen from *Uraniburg* among the *Stars* is *E*, and its Distance from the *Vultur* is the Arch *FE*; but the Comet seen from *Prague*, appears in *C*; and its Distance from the *Vultur* is the Arch *FC*, which is less than the Arch *FE*. But by Observation it has been found, that this Comet, seen from both these Places, seemed to be at the same Distance from the *Vultur*; and therefore the Arches *FE* and *FC* are equal, or rather the same. So great therefore is the Distance of the Comet from the *Earth*, that the Arch *CE* vanisheth, and is altogether imperceptible: But the *Moon* seen from these two Places would appear to have different Distances from the *Vultur*; and so therefore would a Comet, were it as near as she is: This Comet therefore was further distant off than the *Moon*.

The true and the apparent Place of a Comet.

Its Parallax.

A Comet at *D* seen from the Center of the *Earth* would appear in *G*; but from the Surface of the *Earth* at *A* it is observed in *E*: The first is called the Comet's true Place, and the second its apparent Place; and the Distance *GE* between the true and apparent Place, is called the *Parallax* of the Comet: By it a Comet is always depressed more towards the Horizon, than it is in its true Place. Now the *Parallax* of any *Star* is always equal to the Arch which measures the Angle, that the *Earth's* Semidiameter, passing through the Place of the Observator, is seen under from the Comet; as we shewed before, when we treated of the *Parallax* of the *Moon*.

Now if there be no sensible *Parallax*, the Angle under which the Semidiameter of the *Earth* is seen from the Comet, will not be sensible; and therefore the Comets must needs be at a vast Distance from us, since the *Earth* seen from thence appears no bigger than a Point.

A Way to find if a Comet has a sensible Parallax.

By the Help only of a Thread, in a Matter of so great Nicety, we may find out if a Comet have any sensible *Parallax*: For a Comet, just before it disappears, goes so slowly, that it scarce seems to move; and it may be twice observed in this Man-

ner:



ner: First, when it is very high above the *Horizon*, take any two *Stars* between which the Comet lies in a right Line parallel to the *Horizon*, which, by extending the Thread directly before the *Stars*, may be easily tried; afterwards, when the Comet approaches near to the *Horizon*, by extending the Thread we must again try, if it still keeps in a right Line between the same two *fixed Stars*. Now if there be any sensible *Parallax* which depresses the Comet, it cannot be seen in the same Right Line as before; and therefore if it keeps the same Position as to those *Stars*, it is a convincing Argument, that the Comet has no sensible *Parallax*, and must therefore be at a prodigious Distance from us. We need not here fear any Error arising from Refraction, which always raises the *Stars*, and makes them appear more elevated above the *Horizon* than they are; for this Refraction equally affects both Comet and *Stars*; and therefore it will not change their Positions in respect of one another.

A Comet may likewise be observed when it is near the *Eastern Part* of the *Horizon*, and in a right Line with two *Stars* that are both in the same Circle; which is perpendicular to the *Horizon*: And afterwards, when the *Stars* rise higher, and are not in the same vertical Circle as before, if it appear still to be in the same Line with them, it can have no sensible *Parallax*; and therefore its Course must be very high in the Heavens. But if it should be found more depressed than to appear in the right Line that joins the *Stars*, then the Comet must needs have a *Parallax*. If, while these Observations are making, the Comet should have a proper Motion of its own, there must be made an Allowance for that Motion, according to the Time between the two Observations.

As the want of a diurnal *Parallax* was an Argument for placing Comets above the *Moon*, so their being subject to the *Parallax* of the annual Orb is a convincing Proof of their descending into

*Another  
Method for  
the same.*

*Comets are  
affected with  
the Parallax  
of the annual  
Orb.*



Lecture XVII. into the planetary Regions ; for Comets which have a Motion forward, according to the Order of the

Signs, near the Time of their disappearing, are all of them either slower than usual ; or even Retrograde, if the *Earth* be between the *Sun* and them ; or they are quicker than ordinary in their Motions, when the *Sun* is between the *Earth* and them : and they appear in *Conjunction* with the *Sun*, as the *Pla-*

*When a Comet is seen Retrograde.* *Comets* are observed to do. On the contrary, those Comets which have their proper Motions Retrograde, or contrary to the Order of the Signs, are quicker than usual when they begin to withdraw themselves, and disappear when the *Earth* is between the *Sun* and them ; or else they slacken their Pace, and seem to move more slowly, when the *Earth* is in the opposite Position. These Changes in their Motions arise from the Motion of the *Earth*, and its various Position, as in the *Planets*, who, according as the Motion of the *Earth* agrees with theirs, or is contrary to it, sometimes appear to go with a retrograde Motion ; sometimes they go slower, and sometimes with a quicker Motion.

IF the *Earth* move the same Way as the Comet does, and hath an angular Motion round the *Sun* quicker than it, so that the right Lines which constantly join the *Earth* and Comet, all converge to Points beyond the Comet : This Comet seen from the *Earth*, upon the Account of his slower Motion, will appear Retrograde ; but if the Motion of the *Earth* be less than that of the Comet, the Motion of the *Earth* takes off from the visible Motion of the Comet, and then the visible Motion of the Comet seems to be slower. But when the *Earth* and Comet have contrary Motions, the Comet's apparent Motion is thereby accelerated.

WE infer the same Thing from the Curvature of a Comet's Way ; for they generally seem to move in great Circles almost as long as their Motion is swift. But at last, when that Part of their apparent Motion which arises from the *Parallax* of the annual Orb, bears a greater Proportion to their



their whole apparent Motion, then they use to deviate from moving in a great Circle; and when the *Earth* moves one Way, they go the contrary: This Deflection or Deviation arises chiefly from the *Parallax* of the annual Orb, and exactly answers to the Quantity of the *Earth's* Motion. And by Observation, it has been found in some Comets so great, as sufficiently to prove that they have descended far below *Jupiter*: And in their *Perigeons* and *Perihelions*, when they are nearest to us, they often come within the Orbit of *Mars*, and even the Orbits of the inferior *Planets*.

WHEN the Comets recede from the *Earth*, and approach the *Sun*, their Lustre and Light is increased, although their apparent Diameters be diminished upon Account of their further Distance from us.

THE Figures of Comets are observed to be very different; for some of them throw forth Beams like Hair every way round them, and these are called *Hairy Comets*. Others again have a long Beard, or rather a fiery Tail, opposite to the Region in which the *Sun* is seen; and they are called *Bearded*, or *Comets with Tails*. Their Magnitude has also been observed to be very different; many of them, without their Hair, appear no bigger than *Stars* of the first Magnitude. But some Authors have given us an Account of others which were much greater; such was that which appeared in the Time of the Emperor *Nero*, which, as *Seneca* relates, was not inferior in Magnitude to the *Sun* itself. So the Comet which in the Year 1652, *Hevelius* observed, did not seem to be less than the *Moon*, though it had not so bright a Splendor; for it had a pale and dim Light, and appeared with a dismal Aspect. Most Comets have a dense and dark Atmosphere surrounding their Bodies, which weakens and blunts the *Sun's* Rays that fall upon it; but within it appears the Kernel or solid Body of the Comet, which, when the Clouds are dispersed, gives a splendid and brisk Light.

*The Figures  
of Comets.*



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Comets have  
their appa-  
rent diurnal  
Motion from  
East to West.

They have  
likewise a  
proper Mo-  
tion of their  
own.

The Method  
of finding  
the Course  
of a Comet.

Plate XVI.  
Fig. 2.

COMETS, since they are at such a Distance from the *Earth*, like all other *Stars*, must have the apparent Motion round the *Earth* from *East* to *West*, which arises only from the Rotation of the *Earth* round its *Axis*. But besides this they have a real and proper Motion of their own, by which they are continually shifting their Place in the Heavens, and have their proper Courses in the Celestial Regions. The Antients were not ignorant of such a Motion; for they never had reckoned them among the wandering *Stars*, unless they had known that, like the *Planets*, they had their peculiar Courses: *Seneca* acknowledged and observed that they had such a Motion, and said, that their Way was in a Right Line; or as the *Astronomers* use to say, in a great Circle. For in the seventh Book of his natural Questions, Chap. 8. he says, "That the Course of a Comet is easy and quiet, that it takes a determined Way: That Comets do not proceed in a confused and tumultuous Manner, as some believe, nor are they driven by turbulent and uncertain Causes." In his 29th Chap. he mentions two Comets, one of which, in the Space of six Months, passed thro' one half of the Heavens. Another, in the Time of the Emperor *Claudius*, was first observed towards the *North*, which by Degrees arose directly higher and higher, till it quite disappeared.

By the means of a Celestial Globe, in whose Surface the *Stars* are rightly placed and painted, by a Mechanical Method, the Way of a Comet may be easily traced in the Heavens. Let there be every Day observed four *Stars* which are round the Comet, and let them be such as the Comet may be in the right Lines which joins the two opposite *Stars*; which may easily be found out by the means of a Thread placed before the Eye, and extended over-against the *Stars* and Comet: For Example, let the Comet's Place be A, between the four *Stars* B, C, D, E, so that the Line joining the *Stars* B and D, may pass thro' the Body of the Comet; and so likewise the Line



Line passing thro' the *Stars* C and E. And therefore upon a Globe, in which are marked these four *Stars* in their proper Places, extend one Thread thro' the *Stars* B and D, and another thro' the *Stars* C, E; and the Intersection of the Threads will give you the Place of the Comet. If this be daily done, and the Place of the Comet be every Day taken, by this means we shall manifestly find out the Course a Comet takes in the Heavens, which will be found to be a great Circle; for all the Points thus mark'd will be found to fall on the Periphery of a great Circle: And having any two Points of this Circle, we shall find its Inclination to the Ecliptick, and the Places of the *Nodes*: for it is only observing where a Thread stretched through the two Points cuts the Ecliptick.

THERE is another Way of finding out the proper Course of a Comet, by observing every Day its Distance from two *fixed Stars*, whose Longitudes and Latitudes are known; from which Distances we can compute the Places of the Comet; and these Places being marked on the Surface of a Celestial Globe, will manifestly shew that the Course of a Comet is in a Portion of a great Circle, excepting that the Motion of the *Earth* will make it appear to deviate a little from it.

*Another Way of doing the same.*

*The Course of a Comet appears nearly to be in a great Circle.*

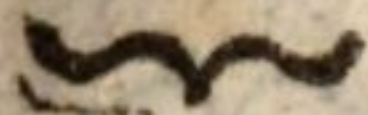
HENCE it is manifest, that the Motion of a Comet is in a Plane, which passes through the Eye of the Spectator, or, more exactly, which passeth thro' the *Sun*; for all visible Motion that is made in such a Plane, however it be inclined to the Ecliptick, will always appear to be in the Periphery of a great Circle. Moreover, the Motion of a Comet is regular and orderly: and tho' it is unequal, yet there is a certain exact Order observed in the very Inequality of Motion. The proper Motion of Comets is not the same in all; but each has its peculiar Course. Some go from the *West* to the *East*, others from *East* to *West*, contrary to the Order of the Signs, and their Direction is contrary to the Way the Planets take, who all move from *West* to *East*: All of them that

*The Motion of Comets is in Planes which pass through the Eye or the Sun.*

*Their Courses various.*

are



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are exactly observed, turn *Southwards* or *Northwards*, with different Inclinations to the *Ecliptick*; and they are not like the *Planets* to be comprehended within the *Zodiack*, but they quickly depart out of it, and with various Motion pass through all the Regions of the Heavens, some with a quicker, some a slower Motion. The greatest Velocity that any we have yet seen has had, was that which was observed by *Regiomontanus*; which Comet moved in one Day full forty Degrees. Some are swiftest in the Beginning of their Appearance, and slacken their Pace as they begin to vanish. Others again in the Beginning and End of their Appearance have a slow Motion; but in the middle Time they are carried with a greater Velocity.

Comets deviate from a Course in a great Circle.

It has been observed, that some Comets for a few Days before they disappeared, did not keep their Course exactly in a great Circle, but did somewhat deviate from it; so that the Angle of the Comet's Orbit and the *Ecliptick*, was found to be different at last from what it was at first: But this Deflection was only apparent, and did not arise from the real Motion of the Comet, but from that of the *Earth*, as we shewed in the inferior and superior *Planets*; whose Distance and Inclination to the *Ecliptick* is various, according to the different Position of the *Earth*, whereas, if they were observed from the *Sun*, any one of them would always appear to move in the same great Circle.

The true Line that a Comet describes.

ALTHOUGH the Motion of a Comet appears to be in a great Circle, yet its true Way may be quite different from a Circle, and may be in very various and different Lines, as either a Right Line, an *Elliptick*, *Parabolick*, or *Hyperbolick Curve*; or it may be any other Curve described in the same Plane: For all Motions in whatever Line the moving Body takes, when it lies in a Plane passing through the Eye, will always be observed to be performed in a great Circle. Many *Philosophers*, and not a few *Astronomers*, have maintained that the



the Comets Motions are rectilinear ; but that which answers best to their Appearance, is a Motion in a parabolick or elliptical Orbit. And if their Orbits be elliptical, they are extremely excentrick ; so that their greater *Axis* bears a very considerable Proportion to their lesser ; upon which Account they differ very much from the *Planets*, which, though they move in elliptical Orbits ; yet they are so little excentrick, that they differ but a small Matter from Circles. Now the *Sun* resides in the common *Focus* of the Orbits of both Comets and *Planets*. And the Comets observe the same Law in their Circulations round the *Sun* as the *Planets* do ; that is, they move at such a Rate in their Orbits, that the Line which joins the *Sun* and them, does always describe Areas or Spaces proportional to the Times ; and therefore upon the same Account as the *Planets*, they likewise must have a Gravity or Propension towards the *Sun*.

WHEN the Comets come to the inferior Parts of their Orbits, and descend towards the *Sun*, or are just ascending from him, then only they become visible ; afterwards departing from the *Sun*, and ascending higher in their Orbits, they run out into far distant Regions, and withdraw themselves from our Sight ; for upon the Account of their going further off the *Sun*, the Light they receive from him is thereby much weakned ; and because likewise of their greater Distance from us, their apparent Diameters become constantly less, till at last they vanish into a Point, and become invisible. In their *Aphe-<sup>The Comets</sup>* lions, whither they run out into far distant Regions, <sup>when they become visi-  
ble.</sup> because of the great Excentricity of their Orbits, they have a very slow Motion ; but in their *Peri-<sup>When invi-  
sible.</sup>* helions, where they come near the *Sun*, they move with a quick Pace.

LET *S* be the *Sun*, *APDG* the elliptick Orbit of a Comet ; *TCE* the Orbit of the *Earth*. If we should suppose the *Semi-Axis* of the Comet's Orbit to be 100 times greater than the *Semi-Axis* of the *Earth's* Orbit, or, which is the same, than  
O 4 its



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Plate XVI.  
Fig. 3.

its mean Distance from the *Sun*, that Comet would not complete its Revolution in less than 1000 Years; for the Squares of the periodical Times of the *Earth* and Comet must be as the Cubes of their mean Distances from the *Sun*; and the Comet becomes visible only for that Part of its Period, wherein it descends towards the *Sun*, and approaches near the *Earth*, as in F; and then, after it hath passed its *Perihelion*, constantly rising higher from the *Sun* about G, it will begin to vanish, and will not be visible without a Telescope. If the *Aphelion* Distance be to the *Perihelion*, as 1000 is to one, the Velocity of a Comet in the *Perihelion* will bear the same Proportion to the Velocity at the *Aphelion*. For the Area A S B must be but equal to the Area P S D, if the Arches A B and P D be described by the Comet in equal Times; and then the Arch P D must be greater than A B, in the same Proportion as A S is greater than P S. This is the Proportion of their absolute Velocities. But their angular Velocities about the *Sun* are in a duplicate Proportion of these Distances, or as 1000000 to 1; so that while the Comet in its *Perihelion* describes one Degree with its angular Motion, when it ascends to its *Aphelion*, it will describe in an equal Time but the  $\frac{1}{1000000}$  of a Degree; so that there it may have so slow a Motion, that it will require several Years before it can complete a Degree of angular Motion.

The small  
Portion of  
the Ellipse  
which a Co-  
met describes  
while it is  
seen by us,  
may be  
esteemed as  
a Parabola.

SINCE the elliptick Orbits of Comets are all of them very Excentrick, those Portions of them wherein they become visible to us, may pass for Parabola's. For if one of the *Focus*'s of an Ellipse recede infinitely from the other, this Ellipse will thereby be changed into a Parabola; as when the two *Foci* come together and coincide, the Ellipsis is changed into a Circle. Now by considering that Portion of a Comet's Orbit which is near the *Perihelion*, as a Piece of a Parabola near its *Vertex*, the Calculation of their Motions becomes much easier; and upon that *Hypothesis* our most skilful *Astronomer* and *Geometer* Dr. *Halley*, has constructed



constructed and calculated a Table, by which the Motions of all Comets are easily computed, and the Calculations founded upon this *Hypothesis* do exactly agree with the Observations made on them. Dr. *Halley* himself, having computed the Motions of several Comets, and compared them with Observations made by others, has found there was so nice a Correspondence between them, that the Calculation scarce ever differed from the Observation above three Minutes. By which Examples it is abundantly manifest, that this Theory satisfies all the Appearances and Motions of Comets, with no less Exactness than the Motions of the *Planets* are accounted for and foretold from the Theories we have of them, whose computed Places do sometimes differ from Observations as much as in Comets. And altho' the Motions of Comets are much more unequal than those of the *Planets*, yet this Theory does wonderfully answer all their Appearances: And therefore since it is built upon the same Laws as the Theory of the *Planets*, and the Motions of one governed by the same Physical Causes as they of the other are; and since it accurately answers all Observations of *Astronomers*, it cannot but be the true Theory.

ALTHO' all the *Planets* have their proper Motions from *West* to *East*, yet many Comets have been observed to hold on in a contrary Course, and have been seen to go from *East* to *West*, with a very great Degree of Velocity. Such was the Course of the Comet which *Regiomontanus* observed in the Year 1472, that described 40 Degrees of a great Circle in one Day. Hence we can positively conclude, that there are no *Vortices*, or Whirlpools of fluid Matter in the Heavens, which, according to the Opinion of some *Philosophers*, carry the *Planets* round the *Sun*: For if there were any such Whirl-pools, when the Comets come down and enter within the Region of the *Planets*, they must be necessarily driven out of their Course by the rapid Motion of the Solar Vortex, as by a mighty Torrent, which near the

Many Comets move from East to West.

Therefore there can be no Vortices.

Earth



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There is no  
Fluid in the  
Heavens  
which has a  
sensible Den-  
sity.

*Earth* is of such Force, that it carries it above 20000 Miles in an Hour: And who can think, that so rapid a Stream would not affect the Comets, and when they have a Motion contrary to its Motion, soon destroy it? For what can resist so violent a Torrent of fluid Matter? Now many Comets have been observed to take a Course directly contrary to this Stream, and which perform their Motions with the greatest Freedom and without the least Resistance, just after the same Manner as they would do in a void Space, where there is nothing to withstand them. But this is plainly repugnant to the Nature of a *Vortex*; for that *Medium* which can put the *Planets* in Motion, would without all Question, set all other Bodies which swim in it a going the same Way. But since there is nothing like this observed in Comets, we must acknowledge that in the Heavens there is no Resistance, and therefore no *Medium* or Fluid, which compared with our Air hath any sensible Density: For our Air gives a very considerable Resistance to all Bodies that move in it.

LET not therefore the *Cartesians* and *Leibnicians* talk to us any more about their *Vortices*; for the Appearances of the Celestial Bodies are such as that we can by no means admit of them; so that they who labour to explain the Motions of the Heavens by them, do only amuse us with Trifles and Impossibilities; and it is to no purpose to trouble ourselves any longer with their Fancies, since there is Demonstration against them.

SINCE the Resistance of a *fluid Medium* arises chiefly from its Density, it from thence necessarily follows, that where there is no sensible Resistance of the *Medium*, there the *Medium* must have no sensible Density; and therefore since, in the Heavens the Comets suffer no sensible Resistance, but exert their Motions with the greatest Freedom, as if they were in a perfect Void or *Vacuum*, there likewise the Density of the *Medium* must be the least that can be, or next to Nothing. And who knows but the *Medium* in the Heavens may be so rare  
and



and fine, that if you except the *Planets*, and their *Atmospheres*, the Matter which is diffused thro' all the rest of the Planetary Region, or our solar System, may not be so much as that which is contained in an Inch of our common Air. For this we have demonstrated to be possible in our Physical Lectures. Lecture XVII.

THE *Philosophers* after this need trouble us no longer with their Metaphysical Quirks against a *Vacuum*; for they seem to be very like the Quibbles of the antient *Sophists* against the Possibility of Motion: And as *Diogenes* confuted those *Sophists* by rising and walking, so we may answer the *Cartesians* by bidding them look up into the Heavens; and there, notwithstanding their nice and subtle Arguments, they will find, from the Appearances and Motions there observed, a manifest Demonstration for the Necessity of a *Vacuum*. A Vacuum or Void is proved.

FEW Comets have been observed before their Descent to the *Sun*, and their Return from their *Perihelion*. For before they have been considerably heated in the Neighbourhood of the *Sun*, they scarcely project a Tail to make them remarkable: But after they have been well heated in their *Perihelion*, then they generally send forth a large shining and fiery Tail, which seems to consist of a very fine, rare and luminous Matter, which is attenuated by the great Heat of the *Sun*, and projected with an immense Force from the Body of the Comet. The Cause of this Projection perhaps may be very like that whereby a great Quantity of fine lucid Vapour was lately thrown out from the *Earth*, to an immense Height above the Air, so that it was visible through the greatest Part of *Europe*; and in Figure and Lustre looked very like the Tails of Comets, but the Matter being spent, it soon vanished. The Tails of Comets.

IT is very remarkable, that all Comets have their Tails in Opposition to the *Sun*; that is, if the *Sun* be in the *West*, the Tail is projected *Eastward*; or if the *Sun* be in the *East*, the Tail looks *Westward*; at Midnight the Direction of the Tail is to the The Tails of Comets always opposite to the Sun.



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the *North*. These Tails grow bigger as they descend to the *Sun*, and at the *Perihelions* they are biggest; and as they go further off from the *Sun*, and cool by Degrees, the Tail lessens, till at last it is contracted within the Comet's Atmosphere.

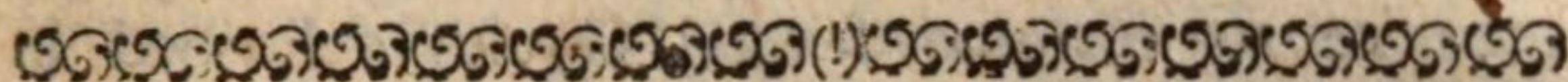
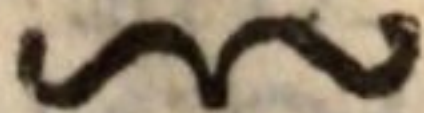
COMETS which have short Tails, do not throw forth the Matter of them with a very quick Motion, in a continual Stream from their Bodies; for then they would soon be dissipated and vanish: but these Tails seem to be rather permanent and fixed Columns of Vapour and Exhalations, which being propagated from the Body with a slow Motion upwards, and retaining still the Motion which they had impressed in them to go along with the Comet, they still continue to move on with the Body through the Celestial Regions. From hence we may likewise conclude, that in the Heavens there is no Resistance; for in them not only the solid Bodies of *Planets* move, but also the thin and fine Vapours which arise from Comets feel no Resistance; but move with the greatest Freedom, and for a long time preserve their Motions.

THE great Comet which appeared in the Year 1680, after its Departure from the *Perihelion*, projected such a Tail as extended itself more than forty Degrees in the Heavens; nor can this be a Wonder, for it was so near the *Sun*, that its Distance from his Surface at the *Perihelion* was but a sixth Part of the Diameter of the *Sun's* Body; and therefore the *Sun* seen from the Body of the Comet, would appear to fill the greatest Part of the Heaven, and its apparent Diameter would not be less than 120 Degrees; and therefore the Heat it received from thence must be prodigiously intense beyond Imagination; for it exceeded above 3000 times the Heat of red hot Iron. And therefore we must allow, that the Bodies of Comets, which can bear so great a Heat, must be very dense, hard and durable Bodies: For if they were nothing but Vapours and Exhalations raised from the *Earth* and *Planets*, as some have dreamt, this  
Comet,



Comet, at so near an Approach to the *Sun*, must have been quite destroy'd and dissipated.

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## LECTURE XVIII.

*The Spherical Doctrine, or, Of the Circles of the Sphere.*



SINCE every Spectator, in whatever Place of the vast Expansion of the Universe he resides, is always in the Center of his own View, when he looks up at the Heavens, he will see it as a

*The Eye of a Spectator is always in the Center of his own View.*

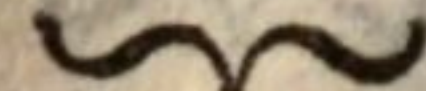
Concave Spherical Surface, whose Center is the Eye, which Surface is every way bespangled with an innumerable Multitude of shining *Stars*: And the Spectator will likewise observe, that all the Heavenly Bodies perform their Motions, whether real or apparent, in this Surface. Now since the Distance of the *Earth* from the *Sun* is but a Point, as it were, in Comparison of the immense Distance of the *Starry Firmament*, in whatever Point of its Orbit the *Earth* is placed, there will be the same Prospect of the Heavens, the same Position and Magnitude of the *Stars* and Figures of the Constellations, as a Spectator would observe, did he reside in the *Sun*; and therefore it is the same Thing as to these Appearances, whether the Center of the Universe or Heavens, be placed in the *Sun* or *Earth*: And if we imagine several Circles to pass thro' the *Earth*, and to have its Center for theirs, and others parallel to them to pass thro' the *Sun*, these Circles in the Heavens will seem to coincide, because their Distance will vanish in respect of the immense Distance of the *fixed Stars*; and those Circles which are drawn thro' the *Sun* and *Earth* on

*It is no Matter whether the Center of the Heavens be considered to be in the Sun or Earth.*

parallel



Lecture XVIII. parallel Planes, will appear to pass thro' the same Stars in the Heavens.

  
A great Circle.

FOR the better determining the Places of all sort of Stars, and observing of their Motions, it is requisite to imagine several Circles described in the Heavens, some of which are great Circles, others of a less Size. A great Circle is the greatest that can be described on the Surface of the Sphere, and divides it into two equal Portions, and has likewise the same Center that the Sphere has; and therefore all great Circles, having the same Center, must cut each other into equal Portions or Semi-circles.

The lesser Circles.

THE lesser Circles divide the Sphere into unequal Portions, and have not the same Center that the Sphere has; and they take their Denomination from some great Circle to whom they are parallel, as the *Æquator*, *Horizon*, or *Ecliptick*.

The Poles of Circles.

EVERY Circle of the Sphere hath two Poles, which are Points on the Surface of the Sphere, which are at equal Distances from all the Points of the Circle; and they are placed in the Surface where a Line from the Center perpendicular to the Plane of the Circle meets with the Surface of the Sphere, when the Line is produced both ways.

Circles moveable and immovable.

SOME Circles of the Sphere depend only upon the Place of the Spectator, and have a Regard to his Position; others again are produced by Motion: The first are called moveable Circles, because, as the Place of the Spectator is changed, so are they, and move along with him. The second are called immovable, and are supposed to be fixed to the same Points of the Heavens.

THE Circles which owe their Origin to Motion, are chiefly the *Ecliptick* and *Æquinoctial*, and their *Parallels*. For because the *Earth* is carried round the *Sun* in a Year, a Spectator in the *Sun* will see the *Earth* describe a great Circle in the Heavens or *Starry Firmament*, which we call the *Ecliptick*; and it is the very same Circle which we in the *Earth*



*Earth* observe the *Sun* to move in by an apparent Motion, likewise in the Space of a Year, as we shewed before. The Ecliptick is divided into twelve equal Parts, which are called the twelve Houses or Signs, and they have their Names from the neighbouring Constellations: They begin at the Vernal Intersection of the *Æquator* and Ecliptick, and are reckoned from the *West Eastwards*, as the *Sun* seems to move. The first three Signs are ♈ ♉ ♊, which arise from the *Æquinoctial*, and ascend *Northwards* to the Point of the Summer Solstice. The next three are ♋ ♌ ♍, which begin from *Cancer*, and descend again towards the *Æquinoctial*, till they come to the Autumnal Intersection. The third Ternary of Signs consists of ♎ ♏ ♐, which begin at *Libra*, and departing from the *Æquinoctial Southward*, reach the Winter Solstice. ♑ ♒ ♓ make the fourth, which begin at *Capicorn*, and end in the Vernal *Æquinox*. Each Sign is divided into 30 Degrees, and consequently the whole Ecliptick into 360. The *Sun* is always observed in this Circle, and never deviates in the least from it, as the *Planets* do, which go sometimes on one Side of it, sometimes on the other, thro' a Space of about eight Degrees; and therefore, if we imagine a broad Circle or Zone of about sixteen Degrees in Breadth, which the Ecliptick cuts in the Middle, this will be the Space wherein the *Planets* perform all their Motions, and by the *Greeks* it is called the *Zodiack*, by the *Latines* *Signifer*, or the Sign-bearer, because of the Signs placed within it.

IF we imagine an indefinite Number of great Circles to be drawn thro' the Poles of the Ecliptick, and intersecting of it, these Circles are called *Secondaries of the Ecliptick*; for by them every *Star* and Point of the Heavens are reduced to the Ecliptick, and have their Places in regard to it determined in the Heavens. For the Place of any *Star* reduced to the Ecliptick, is that Point where the Secondary passing thro' the *Star* intersects the Ecliptick. The Arch between this Point and the Beginning of ♈, or the Vernal Intersection, and counted *Eastward*



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*The Longitude and Latitude of a Star.*

*Eastward* is called the Longitude of that *Star*, as the Arch of the Secondary between the *Star* and the Ecliptick is called the Latitude of that *Star*, and is either *North* or *South*; for the Ecliptick divides the *Starry Firmament* into two *Hemispheres*, *North* and *South*.

*The Primum Mobile.*

SINCE the *Earth* turns round its own *Axis*, from thence it comes that the Inhabitants thereof see the Heavens and all the *Stars* revolve round the *Earth* in the Space of twenty-four Hours from *East* to *West*; which apparent Motion is called the diurnal, or daily Revolution of the Heavens, and was conceived to be by the Force of a moving Sphere called the *Primum Mobile*, or First Mover, which carried the whole Heavens round with it about an *Axis*, which coincides with the *Axis* of the *Earth* produced, as if the *Earth* itself had no Motion, but the Heavens were volvible. The great Circle which is exactly between the two *Poles* of the *Earth*, or at equal Distance from both, is called the *Earth's Æquator*; and if we imagine the Plane of this Circle extended or produced to the Heavens, it will there make the Celestial *Æquinoctial Circle*, or the *Æquator* in the Heavens; and all the *Stars*, and every Point of the Heavens, except the two *Poles*, will seem to describe by their apparent Revolution either this Circle, or a lesser parallel to it; which Circles are either bigger or lesser, according as the *Stars* which seem to describe them, are more removed or nearer to the *Poles*.

*The Æquinoctial.*

THE *Æquinoctial* and Ecliptick being both great Circles, will cut each other into Semi-circles, and their common Intersection will always keep parallel to itself, and will constantly be directed to the same Point of the Heavens; for we here abstract and consider as nothing that very small Motion, whereby the *Axis* of the *Earth* falls backward, and this Intersection equally with it. And therefore, whenever the *Sun* is observed in the Point of the Ecliptick, where this Intersection is, that is, when the *Earth* is really in the opposite, the *Sun* then by this apparent diurnal Motion will describe

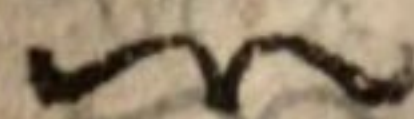


scribe the Equinoctial Circle in the Heavens; and there being two Points of Intersection, the *Sun* will be observed to revolve in the Equinoctial twice every Year; that is, when he is in the two Intersections, Vernal and Autumnal, at which Times all the Inhabitants of the *Earth* will have their Days and Nights equal; upon which Account this Circle has got the Name of the *Æquinoctial*. The Angle which the Ecliptick and the *Æquator* make at the Points of Intersection, is about  $23\frac{1}{2}$  Degrees. The *Sun* leaving these Intersections by an apparent Motion, declines every Day from the Equinoctial Circle more and more towards the *North* or *South*, till he comes to the ninetieth Degree from the Intersections, where he appears to be  $23\frac{1}{2}$  Degrees distant from the Equinoctial, which is his greatest Declination: For from thence he begins to return again towards the Equinoctial; and therefore the two lesser Circles, which the *Sun* at his greatest Declination seems by his diurnal Motion to describe, are called the *Tropicks*, from a *Greek* Word which signifies to return: This, upon the *North* Side of the Equinoctial, is called the *Tropick* of *Cancer*; the other, on the *South* Side, the *Tropick* of *Capricorn*. How this apparent Motion of the *Sun*, and constant Change of his Declination, arise from the real Motion of the *Earth*, the *Sun* himself being all the while at Rest, we have already explained in our seventh Lecture.

THERE are two remarkable lesser Circles of the Sphere, which are parallel to the Equinoctial; and these are described by the apparent diurnal Motions of the two *Poles* of the Ecliptick round the *Poles* of the Equinoctial, from which they are distant  $23\frac{1}{2}$  Degrees. They are called the two polar Circles; this in the *Northern* Sphere is named the *Arctick* Circle, from the two *Bears* which lie near it; the other Circle on the *South* is called the *Antarctick*, or Circle opposite to the *Arctick*.

IF thro' the *Poles* of the World, or of the Equinoctial, there be conceived innumerable great Circles to be drawn, they are called Secondaries of the Equinoctial.



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*The right  
Ascension  
and Declination of  
a Star.*

*The two  
Colures.*

*The Longi-  
tudes and  
Latitudes of  
Places.*

the Equinoctial, by the Help of which the Position of every Point of the Heavens, in regard to the Equinoctial, is determined, as before they were determined by the Secondaries of the Ecliptick, in regard to the Ecliptick: And the right Ascension of a *Star*, or Point in the Heavens, is an Arch of the Equinoctial, between the Beginning of *Aries* and the Point where the Secondary, passing thro' the *Star*, cuts the Equinoctial. The Declination of a *Star* or Point is the Arch of the Secondary intercepted between the *Star* and the Equinoctial, which is likewise as the Latitude either *North* or *South*, as the *Star* declines towards the *North* or *South Pole*: From hence these Secondaries are called Circles of Declination. And the two chief of them are the two Colures, one of which, passing through the two Equinoctial Intersections, is called the Equinoctial Colure; and the other, which cuts the former at right Angles, and passes thro' the *Poles* of the Ecliptick, is called the Solstitial Colure, because it intersects the Ecliptick in the Points which are at the greatest Distance from the *Æquator*; to which when the *Sun* comes, he does not sensibly for some Days change his Declination, but seems to stand without approaching to, or receding from the Equinoctial; and therefore these Points are called Solstices.

THAT Circle which is on the Surface of the *Earth*, exactly in the Middle between the two *Poles*, is the *Earth's* *Æquator*; and by the Production of it we shewed, that the Celestial Equinoctial was formed. And as the Places of all the *Stars* in the Heavens are determined by their Longitude and Latitude, in regard to the Ecliptick and its Secondaries; so by the terrestrial *Æquator* and its Secondaries, drawn thro' the *Poles* of the *Earth*, the Positions of Cities and Places upon the Surface of the *Earth* are determined according to Longitude and Latitude. A Secondary of the *Æquator*, passing thro' any Place on the *Earth's* Surface, is called the Meridian of that Place; because that when, by the Rotation of the *Earth* round its *Axis*, the Plane



Plane of that Meridian comes to pass thro' the *Sun*, then the Inhabitants under this Meridian have Mid-day. The Longitude of any City or Place is an Arch of the *Æquator* intercepted between a certain Point where some fixed Meridian passes, which is called the first Meridian, and the Meridian of the Place. The ancient *Geographers* made the first Meridian pass through some known Place, which was as far *Westward* as they knew, and from thence they reckoned the Longitude of all Places constantly *Eastward*: But since by Navigation it has been discovered, that there is no Place in the *Earth* that can be esteemed the most *Westerly*, so that there is not another more *Westward* beyond it, this way of computing the Longitude from a first Meridian hath been generally laid aside; and now each *Geographer* determines the Longitudes of Places in regard to the Longitude of the chief City of the Country where he dwells. The Latitude of a Place is an Arch of the Meridian of that Place intercepted between the Place and the *Æquator*, and is either *North* or *South*, as the Place lies on the *North* or *South* Side of the *Æquator*.

OF the Inhabitants of the *Earth* compared with one another, in regard to their Meridians and Parallels, some are called *Periæci*, that live under the same Parallel, but in the opposite Semicircles of the same Meridian; both of them have the Seasons of the Year the same, the *Sun* by its annual apparent Motion coming to or receding from the Vertex of both Places at the same Time of the Year; but they change their Turns of Night and Day, so that when it is Mid-day to the one, it is Mid-night to the other. Others again are called *Antæci*, whose Habitations lie in the same Semicircle of the Meridian, but in opposite Parallels, and both of them have Mid-day and Mid-night at the same Instant of Time; but the Seasons of the Year are different, it being Summer to one, when it is Winter to the other. Lastly, there are the *Antipodes*, whose Habitations being situated in both opposite Parallels and opposite Meridians,

The Periæci;

The Antæci;

The Anti-  
podes.



Lecture XVIII. have their Feet directly opposite to one another in a Line passing through the Center of the *Earth*; and they have not only their Days and Nights directly contrary, but also the Seasons of the Year: When it is Summer in the one, it is Winter in the other Place; and when Mid-day in the first, the second reckons Mid-night.

The five Zones.

THE four lesser Circles in the Surface of the *Earth's* Globe, which lie directly under the Circles of the same Name in the Heavens, viz. the two *Tropicks* and *Polars*, divide the *Earth* into five Portions, which are called *Zones*; of which the Torrid is that which is bounded on each Side by a *Tropick*, and was believed by the Ancients to be not habitable, by reason of the violent Heats: But our modern Travellers and Voyagers have discover'd this Tract of the *Earth's* Surface to be the most fruitful and delightful of all, abounding not only with the Things that are necessary, but such likewise as conduce to the Satisfaction and Pleasure of Life; upon which Account it is very well stored with Inhabitants. There are two cold *Zones* which the polar Circles comprehend; in the Middle of the one lies the *Arctic Pole*, of the other the *Antarctic*, and in them the Cold is so excessive, that they are scarcely habitable. Besides these, between the Frigid and the Torrid *Zone*, on each Hand lie the two temperate ones; that on the *North* is possessed by us, the other our *Antipodes* keep. *Virgil* elegantly describes these five *Zones*.

*Quinque tenent Cælum Zonæ, quarum una corusco  
Semper Sole rubens, & torrida semper ab igne;  
Quam circum extremæ dextra lævaq; trabuntur,  
Cærulea glacie concreta, atq; imbris atris.  
Has inter mediamq; duæ mortalibus ægris  
Munere concessæ Divûm.*

The Amphiscii.

THE Inhabitants of the torrid *Zone* are called *Amphiscii*, having their Meridian Shadows at different Times of the Year projected towards both *Poles*; but



but when the *Sun* comes to be Vertical to them, then they have no Shadow, and are *Ascii* or Shadowless, nothing that stands perpendicularly upwards having a Shadow at Noon. We who live in the temperate *Zones* may be named *Heteroscii*, having our Meridian Shadow projected only towards one *Pole* throughout the whole Year. But the miserable People of the two Frigid *Zones* are called *Periscii*, because the *Sun* not setting upon them, their Shadow turns quite round in the Space of twenty-four Hours.

Lecture XVIII.

The Ascii.

The Periscii.

THE two Circles which we conceive to be immoveable, and determined by their respect to the Spectator, are the *Horizon* and Meridian. The *Horizon* is that great Circle which any one, when he is placed in a large extended Plane, or in the open Sea observes, terminating or bounding his Sight every where round him, by which the visible Heaven is distinguished and separated from the invisible. This *Horizon*, being discovered by our Senses, is called the sensible *Horizon*, from which the rational *Horizon*, parallel to it, is distant by the Semidiameter of the *Earth*, through whose Center it passes: For the *Astronomers* reduce the Appearances of the Heavens to a spherical Surface, which is not concentrical to the Eye, but to the *Earth*.

The Horizon sensible and rational.

'Tis true, these two *Horizons*, produced to the *fixed Stars*, will appear to coincide into one, since the *Earth*, compared to the Sphere in which the *fixed Stars* appear, is but a Point; and therefore the two Circles, which are but a Point distant from each other, may be well considered as coinciding into one. There are two *Poles* of the *Horizon*; the one is the Point of the Heavens which is directly over the Head of the Spectator, and is called the *Zenith*; the other directly opposite, under his Feet, is named the *Nadir*; and innumerable Circles, drawn thro' these *Poles* to the *Horizon*, are styled *Vertical Circles* or *Azimuths*. Among them there are two particularly remarkable, one of which is the Meridian, and the other is the *Prime Vertical*; the first passes thro' the *Poles* of the Equator and the *Zenith*, and cuts

Zenith and Nadir, the Poles of the Horizon.



Lecture XVIII. the *Horizon* in the Points of *North* and *South*; the other passing thro' the *Zenith* cuts the former at right Angles, and marks upon the *Horizon* the Points of *East* and *West*. These Circles divide the *Horizon*, at their Intersections with it, into four Quarters, each of which is again subdivided into eight Parts; and consequently the whole *Horizon* is divided into thirty-two Parts, which are called the *Rhumbs* or Points of the Compass.

The Altitude  
or Depression  
of a Star.

THE Altitude or Depression of any *Star* is an Arch of the Vertical intercepted between the *Horizon* and the *Star*.

The Ampli-  
tude.

AGAIN, the *Azimuth* of a *Star* is an Arch of the *Horizon*, intercepted between the Points of *North* or *South*, and the Point where the Vertical passing through the *Star* cuts the *Horizon*, and is either *Easterly* or *Westerly*. The rising or setting Amplitude of a *Star* is an Arch of the *Horizon* intercepted between the Points where the *Star* riseth or setteth, and the Points of *East* or *West*; and this Amplitude is either *North* or *South*, according as the *Star*, at rising or setting, is to the *North* or *South* of those Points.

The Culmi-  
nation.

As in the *Horizon* all the *Stars* first appear and disappear, so in the Meridian Circle they all arise to their greatest Height or Altitude, where they are said to *Culminate*; so likewise they are at their greatest Depression below the *Horizon*, when they arrive at the same Meridian. Now since the Meridian makes Right Angles both with the *Æquator*, and *Horizon*, it will divide the Segments of the *Æquator* and all its Parallels, as well those that lie above the *Horizon* as those which are below it, into equal Portions; and therefore the Time between the rising of a *Star*, and its Culmination or Arrival at the Meridian, will be equal to the Time between this Culmination and its Setting; and because the *Sun* every Day describes some Parallel by its apparent diurnal Motion, when the *Sun* comes to the Meridian at any Time, it will be then Mid-day; and Mid-night, when he arrives at the same Meridian below the *Horizon*; and



and from thence this Circle has its Name. The Lecture *Ninetieth* or *Nonagesimal Degree* is that Point of the XVIII. Ecliptick which is 90 Degrees distant from the Intersections of the *Horizon* and Ecliptick, and the Altitude of this Point is the Measure of the Angle of the *Horizon* and Ecliptick. The *Medium Cæli* or Mid-Heaven, is that Point of the Ecliptick which culminates, or is in the Meridian. In the ascending Signs from ♈ to ♎, the *Nonagesimal Degree* is to the *East* of the Meridian, but in the descending Signs from ♎ to ♈, the *Nonagesimal* lies *Westward* of the Meridian.

The *Horizon* and *Meridian* truly moveable Circles.

ALTHO' we have here considered the *Horizon* and Meridian as immoveable Circles, taking the apparent Motion of the Heavens as real; yet if we speak according to Truth, and the Nature of Things, the *Horizon* and Meridian are the only moveable Circles, and the *Sun* or a *Star* rises not when it ascends, but when the Plane of the *Horizon* descends below it, so that the *Star* or *Sun* becomes visible. So likewise the *Stars* set not by their own Motion, or going down under the *Horizon*, but by the *Horizon's* ascending and getting above them; which Motion of the *Horizon* ariseth from the Rotation of the *Earth*. So also the *Sun* or *Stars* arrive at the Meridian, when the Plane of the Meridian of any Place, having an angular Motion round the *Axis* of the *Earth*, comes to pass through the Bodies of the *Sun* or *Stars*.

The universal Meridian.

SINCE every Meridian finishes its Circulation round the *Axis*, or 360 Degrees in twenty-four Hours, it must each Hour have an angular Motion of 15 Degrees, which is the twenty-fourth Part of 360; and therefore, if we conceive a Circle passing thro' the *Poles*, which makes an Angle of 15 Degrees with the universal Meridian passing thro' the *Sun*, when by the *Earth's* Rotation the Plane of the Meridian of any Place comes to the Plane of this Circle after it has passed the universal Meridian; then the Inhabitants in that Meridian will reckon one Hour after Mid-day, and therefore that Circle is called the Circle of the first Hour. In like Manner, if another Circle be conceived cutting the Equi-

noctial



Lecture  
XVIII.The Horary  
Circles.

noctial in the thirtieth Degree from the universal Meridian, this will be the Circle of the second Hour; and when the Plane of the Meridian of the Place comes to coincide with it, it will be in that Place two of the Clock in the Afternoon. After the same Manner, if through the *Poles*, and every fifteen Degrees of the *Æquator*, we conceive Circles to pass, they are called *Horary* Circles; and they will divide the *Æquinoctial* into twenty-four equal Parts, and each of them in its Order will determine the Hour that is to be reckoned in a Place, when the Plane of the Meridian of that Place comes to coincide with that Circle. So, for Example, when the Meridian of the Place comes to the Circle which makes seventy-five Degrees with the universal Meridian, the Hour then counted in that Place will be the fifth from Noon. But when the Meridian of the Place makes an Angle of ninety Degrees with the Meridian passing through the *Sun*, then it will be the sixth Hour. But on the other Hand, if we should imagine the Meridian of the Place to be immoveable, and that a Circle passing through the *Poles* and the *Sun* should together with the *Sun* turn round the *Axis*, as it appears to do; when the Plane of this Circle, in which the *Sun* resides, coincides with a Circle that makes an Angle of fifteen Degrees with the Meridian of the Place *Westward*, it is then the first Hour after Mid-day; and the Circle with which the Circle passing through the *Sun* and *Poles* does then coincide, is called the Circle of the first Hour. The next Circle to this, which makes an Angle of thirty Degrees with the Meridian of the Place, is the *Horary* Circle for Two of the Clock; and that which makes an Angle of forty-five Degrees with the Meridian of the Place, is the *Horary* Circle for Three of the Clock, &c.

Plate XVI.  
Fig. 4.

IN any Place of the terraqueous Globe, the Height of the *Pole* above the *Horizon* is equal to the Latitude of the Place. Let the Circle *HZQ* be the Meridian, *HO* the *Horizon*, *ÆCQ* the *Æquator*, *Z* the *Zenith*, and *P* the *Pole*: The  
Elevation



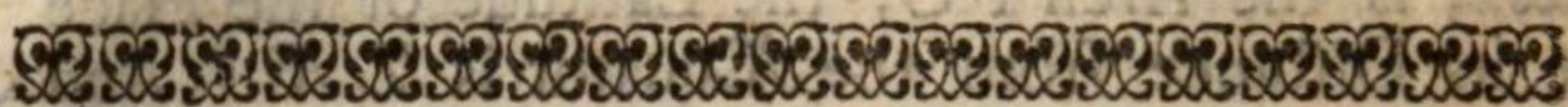
Elevation of the *Pole*, or its Distance from the *Horizon*, is the Arch  $PO$ , the Latitude of the Place or its Distance from the *Æquator* is  $Z\mathcal{A}$ . And because the Arch  $P\mathcal{A}$  between the Pole and the *Æquator* is a Quadrant, or fourth Part of a Circle, and the Arch  $ZO$ , from the *Zenith* to the *Horizon* is likewise a Quadrant, these two Arches  $Z\mathcal{A}$  and  $PO$  must be equal. Take away the Arch  $ZP$ , which is common to both, and there will remain the Arch  $Z\mathcal{A}$  equal to the Arch  $PO$ ; that is, the Latitude of the Place, is equal to the Altitude or Height of the *Pole* above the *Horizon*.

*The Height of the Pole above the Horizon is always equal to the Latitude of the Place.*

HENCE we have a Method of measuring the Circumference of the whole *Earth*, and of knowing how many Miles it is round the *Earth*: For if we go directly *Northward* till the *Pole* be elevated one Degree higher, and then if we measure the length of the Way we have gone *Northward*, and have the Number of Miles it contains, we shall have the Number of Miles in a Degree of a great Circle of the *Earth's* Globe; and this Number multiplied by 360, the Degrees in the whole Periphery, it will give the Length of the Circumference of the *Earth* in Miles. By the most accurate Observations, the Length of a Degree is found to be 69 *English* Miles, which was commonly reputed to be only 60 Miles.





Lecture  
XIX.

## LECTURE XIX.

*Of the Doctrine of the Sphere.*

The Right  
Position of  
the Sphere.



Plate XVI.  
Fig. 5.

An oblique  
Sphere; or  
an oblique  
Position of  
the Sphere.

Fig. 6.

THE Angle contained between the Æquator and the Horizon, is measured by the Arch of the Meridian  $\text{ÆH}$ , which is the Complement of the Latitude to a Quadrant. And therefore if that Angle be right, the Latitude of the Place will be nothing, or the Place will be in the Æquator; or the Æquinoctial Circle will pass thro' the Vertex of the Place, and all the Parallels of the Æquator will be perpendicular to the Horizon; and therefore this Position of the Sphere is call'd a *Right Position*, in which all these Parallels are cut by the *Horizon* into equal Portions; whence the Stars are as long above the *Horizon*, as they lie hid under it: Here likewise the Poles lie in the Horizon without any Elevation, as is manifest by the Figure, where the Point of the Æquinoctial  $\text{Æ}$  is in the Vertex, and the Poles  $\text{P p}$ , in the Horizon. If we go from the Æquator towards either of the Poles, the Æquator will then appear to depart from the Vertex or Zenith, and to come nearer to the Horizon, making with it an oblique Angle; whence such a Situation is called an *oblique Position of the Sphere*, and the Pole towards which we move, doth rise more and more above the Horizon, the nearer we approach it; its Elevation being always equal to the Latitude of the Place, while the other continues as much depressed below it. The Figure does clearly shew this sort of Position, which we and all that live in the temperate Zones obtain, where the Æquator  $\text{ÆQ}$  is bisected by the Horizon, as it is in a right Sphere.



*Sphere* : Wherefore when the Sun, by his apparent Diurnal Motion, describes this Circle, it makes the Day equal to the Night; but the Parallels of the *Æquator*, in this *Oblique Position*, are not cut into two equal Parts by the Horizon; but those which are towards the elevated Pole, each of them have a greater Portion above than under the Horizon: And as each Parallel is nearer the Pole, so much the larger Portion of it stands above the Horizon. But when the Distance of the Parallel from the Pole becomes less than the Elevation of the Pole, or the Latitude of the Place, then that Parallel, and all those included within it, are wholly above the Horizon, no Part of them ever setting under it. The contrary happens in the Parallels which lie towards the depress'd Pole, a smaller Portion of them being above the Horizon, and the greater Part lying under it. And those Parallels, which are nearer to the depressed Pole than the Latitude of the Place, remain perpetually, together with the Stars included within them, under the Horizon, and are never visible to us. Hence it is necessary, since the Sun each Day describes by his apparent Diurnal Motion some Parallel, that from the Vernal *Æquinox* to the Summer Solstice, the Days growing longer and longer, will be continually longer than the Nights; after the Solstice, tho' the Days continue till the Autumnal *Æquinox* to be longer than the Nights, yet they become shorter and shorter, and at the *Æquinox*, they but just equal the Nights: From thence to the Winter Solstice, the Days continually become shorter than the Nights, and are the shortest when the Sun is in that Solstice; but as the Sun leaves it, they increase again, and in the Vernal *Æquinox* the Day is as long as the Night,

IN an *Oblique Sphere* the Stars all obliquely rise and set. And as the *Right Ascension* of a Star is the Arch of the *Æquator* contained between the first of *Aries*, and that Point which comes to the *Meridian* with the Star, or that Point which in a *Right Sphere* rises with the Star: So the Oblique Ascen-



Lecture XIX. Ascension is the Arch of the *Æquator* between the first of *Aries*, and that Point of the *Æquator* which rises together with the Star in an *Oblique Sphere*, and numbred from *West* to *East*, which according to the Obliquity of the *Sphere* is various. The Difference between the Right and the Oblique Ascension is called the *Ascensional Difference*.

IN an *Oblique Sphere* there is one Parallel as much distant from the elevated Pole, as the Place is from the *Æquator*, which is called the Circle of *Perpetual Apparition*, or the biggest of all those which constantly appear; which is such, that all Stars inclosed within it never either rise or set; though they sometimes rise higher, sometimes descend lower towards the Horizon. Towards the other Pole, there is another Circle opposite to this, which is the Circle of *Perpetual Occultation*, within which all the Stars that are contained never rise, but constantly lie hid under the *Horizon*, and so are not to be seen.

A Parallel  
Sphere.

Plate XVI.  
Fig. 7.

IF the *Æquator* makes no Angle with the Horizon, but those two Circles coincide; in such a Situation the Pole and Vertex coincide, and all the Parallels of the *Æquator* become Parallels to the Horizon; and such a Situation is call'd a *Parallel Sphere*, in which no fixed Stars do ever either rise or set, but turn round in Circles parallel to the Horizon. And when the Sun enters the *Æquinoctial*, it then glides the whole Day along the Horizon. When he rises towards the elevated Pole, he never sets, but makes a very long Day of six Months: But when he goes from the *Æquinoctial* towards the depressed Pole, he never rises, and then there is a constant Night of six Months Length. This Position of the *Sphere* belongs only to them who live at the Pole, if any are so miserable as to have such a Place for their Habitation.

Climates  
and Parallels.

THE ancient Geographers divided the *Earth* by Climates and Parallels; for they who live under the *Æquinoctial*, being in a *Right Sphere*, have their Days and Nights equal: If we remove from thence



thence towards either Pole, the Days in Summer become longer than the Nights, and the nearer we approach the Pole, the greater is the Difference between Day and Night, when the Day is at the longest; till we come under the Polar Circles, where there is no Night at all. Hence the Geographers did so divide the Earth by such Parallels, as made the longest Day increase by Quarters of an Hour; that is, each Parallel was so far distant from the next, that the longest Day in the more remote from the *Æ*quator, was a Quarter of an Hour longer than that Day at the Parallel nearer to the *Æ*quator: And therefore reckoning the *Æ*quator as the first Parallel, the second Parallel passed through those Parts of the Earth, where the longest Day was twelve Hours and a Quarter long. Under the third Parallel, the longest Day was twelve Hours and two Quarters. In the fourth, the longest Day was twelve Hours and three Quarters, &c. Now two such Parallels made up a Climate, which were therefore distinguished by the longest Day, increasing half an Hour from the one to the other. Now the Excess of the Solstitial Day above twelve Hours may grow still bigger, till we come to the Polar Circle, where the Sun not setting, makes the Day twenty-four Hours long, which is greater than the *Æ*quinoctial Day of twelve Hours by twenty-four half Hours, or forty eight Quarters of an Hour. From hence we gather, that the Number of Climates between the *Æ*quator and Polar Circles must be twenty-four, and the Number of the Parallels forty-eight.

BECAUSE the Civil Year of the Ancients did not keep Pace or agree with the apparent annual Motion of the Sun; having the Day of the Month, and the Year when any memorable Action fell out, it could not be from thence immediately known in what Season of the Year it was done. And therefore, when the Husbandmen settled the Times for the several distinct Parts of their Business, they could not point out that Time by a certain Day of their *Kalendar*; for the same  
Day

*The rising  
and setting  
of the Stars  
Cosmical,  
Achronical,  
and Helia-  
cal.*



Lecture XIX. Day of the Month was not always in the same Season of the Year: But it was necessary to have more certain Characters and Marks to distinguish Times; and therefore the Writers of Husbandry, Historians and Poets, had recourse to the Risings and Settings of the *Stars*, by them to mark out the Times. And of these Risings and Settings they reckoned three Sorts, *viz.* The *Cosmical*, *Achronical* and *Heliacal*. A *Star* is said to rise or set *Cosmically*, which rises or sets when the *Sun* rises; so that a *Star* which rises or sets in the Morning rises or sets *Cosmically*. A *Star* rises *Achronically*, when it rises while the *Sun* sets, that is, in the Evening, when it is in Opposition to the *Sun*, and is visible all Night.

A *Star* rises *Heliacally*, when after it has been in Conjunction with the *Sun*, and on that Account invisible, it comes to be at such a Distance from him, as to be seen in the Morning before *Sun*-rising, when the *Sun* by his Apparent Motion recedes from the *Star* towards the *East*. But the *Heliacal* setting is when the *Sun* approaches so near a *Star*, that it hides it with his Beams, which keep the fainter Light of the *Star* from being perceived. And therefore the *Heliacal* rising and setting is rather an Apparition and Occultation, than a rising and setting.

ALL the *fixed Stars* in the *Zodiack*, as likewise the superior Planets, *Mars*, *Jupiter* and *Saturn*, rise *Heliacally* in the Morning a little before *Sun* rising, and a few Days after they have set *Cosmically*; because the *Sun* in his Apparent Motion gets before them, moving faster *Eastward*: But they set *Heliacally* in the Evening a little before their *Achronical* setting. But the *Moon*, whose Motion *Eastward* is always quicker than the Apparent Motion of the *Sun*, rises *Heliacally* in the Evening, after the new *Moon* or the Change, when it can be first discovered at *Sun* setting; but the *Moon* sets *Heliacally* in the Morning, when the *Moon* is old and approaching to a Change. The inferior Planets, *Venus* and *Mercury*, which sometimes











times seem to go *Westward* from the *Sun*, and sometimes again have a quicker Motion than he *Eastward*, rise *Heliacally* in the Morning when they are Retrograde; but when they are direct in their Motions, they rise *Heliacally* in the Evening.

IN order to observe the Altitude of the *Sun*, or any *Star*, we use a moveable Quadrant E A D, with fixed Sights A, B, or a Telescope placed along one of its Sides, and a plumb Line A C hanging from its Center. The Quadrant being placed in a Ver-

tical Plane, must be turned upwards and downwards, till the Rays of the *Sun*, passing through the Hole of the first Sight next the Center, fall upon the Hole of the other; or till the *Sun's* Image appears in the *Focus* of the Telescope; and then the Quadrant being kept in this Position, the Plumb Line or Thread, will shew the Arch E C, which measures the Altitude of the *Sun*. For produce A C to the *Zenith* Z, and let A H be an *Horizontal* Line. The Angles E A B and Z A H are equal, being both Right; but the Angles B A C and Z A S are likewise equal, they being vertical to each other: Wherefore, taking away equal Angles, there will remain the Angle E A C equal to the Angle S A H. But the Arch E C measures the Angle E A C, and the Arch of the Vertical between the *Sun* and the *Horizon* measures the Angle S A H; and therefore, this Arch or the *Sun's* Altitude, and the Arch E C, are similar or like Arches. But if the Height of a *Star* be to be observed, instead of the Irradiation of Beams as in the *Sun*, we must look thro' both Sights, or the Telescope for the *Star*; and when we can see it, then the Thread will shew the Altitude of the *Star*. The Meridian Altitude of the *Sun* or *Star* is known by observing when the Altitude is greatest; for then the *Sun* or *Star* attains his greatest Height, being then in the Meridian.

THE Knowledge of the Latitude of the Place is the Foundation of all *Astronomical* Observations, without which we can know nothing; and therefore it is first accurately to be obtained: And because

How to observe the Altitude of the *Sun*, or of a *Star*.

Plate VII.  
Fig. 1.

How to observe the Latitude of a Place.



Lecture  
XIX.

The Inven-  
tion of the  
Meridian  
Line.

cause we have shewed the Altitude of the *Pole* to be always equal to the Latitude, we can best find our Latitude by observing the *Pole's* Height; but because the *Pole* is only a Mathematical Point, and no ways to be perceived by our Senses, we cannot find its Height by the same Method as we did that of the *Sun* or *Stars*. And therefore we must take another Way for finding it. And first we must find the Section of the Plane of the Meridian with the *Horizon*, which Section is called the Meridian Line. This is obtained by erecting a *Gnomon* or Perpendicular upon the *Horizon* in order to cast a Shadow; and at the Foot of the *Gnomon*, at that Point which is directly under the Top-Point, which casts the Shadow, there must be described a Circle, on whose Circumference the Shadow of the Top-Point may fall before Mid-day; and that Point of the Circumference where the Shadow comes, must be carefully marked. Again, after Mid-day observe the Point where the Shadow comes again to the same Circumference; and let the Arch between the two Points of the Shadow be bisected, or cut into equal Parts. A Line drawn from the Center to the Point of Bisection will be the Meridian Line: For the *Sun* before and after Mid-day being equally high, is equally distant from the Meridian, or is in two Vertical Circles, which make on each Side equal Angles with it. Place therefore the Quadrant on the Meridian Line, so that its Plane may be in the Plane of the Meridian; and then take some *Star* near the *Pole*, which never sets, and observe both its greatest and least Altitude. Let the greatest be  $SO$ , and the least  $sO$ ; the Difference of their Altitudes is the Arch  $sS$ , the half of which  $PS$  or  $Ps$ , deducted from the greatest Altitude  $SO$ , or added to the least  $sO$ , will give  $PO$  the Altitude of the *Pole* above the *Horizon*, which is equal to the Latitude of the Place. If the Declination of the *Sun* be known, we may find out the Latitude of the Place in this Manner: Observe the Meridian Distance of the *Sun* from the Vertex or *Zenith*, which is always the

Plate XVII.  
Fig. 2.



the Complement of his Altitude; and add to this the Sun's Declination, when the Place and he are on the same Side of the  $\mathcal{A}$ equator; or subtract the Declination when they are on different Sides, the Sum or Difference is always equal to the Latitude: But when the Declination of the Sun is greater than the Latitude of the Place, which is known from the Sun's being nearer to the elevated Pole than the Vertex of the Place is, as it will often happen in the torrid Zone; then the Difference between the Sun's Declination and the Sun's Zenith Distance is the Place's Latitude.

HAVING once found out the Latitude of the Place, the Obliquity of the Ecliptick, or its Inclination to the  $\mathcal{A}$ equator is easily obtained, by observing about the Summer Solstice the Sun's least Distance from the Vertex: If this Distance be subtracted from the Latitude of the Place, when the Place is nearer to the Pole than the Sun is, the Remainder will shew the greatest Declination of the Sun, which is equal to the Obliquity of the Ecliptick. Most Astronomers make the greatest Declination of the Sun, or the Obliquity of the Ecliptick to be  $23\frac{1}{2}$  Degrees; but the more accurate Observations of our modern Astronomers shew it to be one Minute less.

By the same Method, the Declination of the Sun for any Day, or that of a Star may be taken; for when the Sun or Star is nearer to the  $\mathcal{A}$ equator than the Place, take the Difference between the Latitude of the Place and the Meridional Distance of the Sun or Star from the Vertex, and we shall have the Declination: But if the Vertex of the Place lie between the Sun or Star and the  $\mathcal{A}$ equator, then the Sum of these two Quantities is the Declination.

HAVING the Declination of the Sun, it is easy to find his right Ascension and Place in the Ecliptick, by the Solution of a right angled spherical Triangle. For let  $\mathcal{A}Q$  be the  $\mathcal{A}$ equator,  $\mathcal{A}C$  the Ecliptick,  $S$  the Sun; from which let fall on the  $\mathcal{A}$ equator a Circle of Declination  $SD$ , and then the Arch  $SD$  will

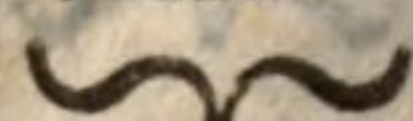
*How to observe the Obliquity of the Ecliptick.*

*How to find the Declination of the Sun or Star.*

*To find the Sun's right Ascension.*

Plate XVII.  
Fig. 3.



Lecture  
XIX.

will be the Sun's Declination. And therefore in the right-angled Triangle  $\triangle AED$  we have  $SD$  and the Angle  $\angle A$ : We can therefore from thence find by spherical *Trigonometry* the Arch  $ED$ , which is the right Ascension of the Sun, and  $AS$ , which gives his Place in the Ecliptick; and likewise the Angle  $\angle ASD$ , the Inclination of the Circle of Declination, or of the Meridian with the Ecliptick. So likewise in the right-angled Triangle  $\triangle AED$ , if we have the Side  $ED$ , which is the right Ascension, the Angle  $\angle A$  being constant and known, we may easily find the Side  $SD$ , which is the Declination of the Point of the Ecliptick  $S$ , which comes to the Meridian together with  $D$ , and is then called the *Medium Cæli*, or Mid-heaven; as also the Angle  $\angle ASD$  the Inclination of the Meridian to the Ecliptick. Or lastly, if  $AS$  the Longitude of the Point  $S$  be known, we can from it find its right Ascension and Declination, together with the Angle  $\angle DSC$ , of the Ecliptick and Meridian.

The apparent Motion of the Sun in the Ecliptick is not equable.

IF the Declination of the Sun by the Method we have shewed be daily observed, we can from thence collect the apparent Motion of the Sun in the Ecliptick, which is always equal to the Motion the Earth really has in the same Time. Now, by Observation, we find that the Sun does not move equably, or always with the same Velocity in the Ecliptick: And therefore the real Motion of the Earth must be unequal, and not constantly the same; in the Summer Solstices the Earth has a slower Motion, in the Winter Time it moves quicker: And this happens, because the Earth by its real Motion is carried in the Perimeter of an Ellipse, which has the *Sun* in one of its *Foci*; round which it revolves in such a Manner, that a Line drawn from the Sun to the Earth, and by an angular Motion carrying the Earth along with it, doth always sweep or describe Elliptick *Area's* or Spaces proportional to the Times in which they are described.

HAVING the Place of the Sun in the Ecliptick, by the Help of it, and a good Pendulum Clock, we may



may find the right Ascensions of all the Stars: For which Purpose the Motion of the Clock must be so adjusted, that the Hand may run thro' the twenty-four Hours in the Time that a Star leaving the Meridian will arrive at it again; which Time is somewhat shorter than the natural Day, because of the Space the Sun moves thro' in the mean Time Eastward. The Clock being thus adjusted, when the Sun is in the Meridian, fix the Hand to the Point, from whence we are to begin to reckon our Time; and then observe when the Star comes to the Meridian, and mark the Hour and Minute that the Hand then shews: The Hours and Minutes describ'd by the Index, turn'd into Degrees and Minutes of the *Æquator*, will give the Difference between the right Ascension of the Sun and Star; which Difference, being added to the right Ascension of the Sun, will give the right Ascension of the Star. Now if we know the right Ascension of any one Star, we may from it find the right Ascensions of all the others which we see, by marking the Time upon the Clock between the arrival of the Star, whose right Ascension we know, to the Meridian, and another Star, whose Ascension is to be found. This Time converted into Hours and Minutes of the *Æquator*, will give the Difference of right Ascensions; from whence, by *Addition*, we collect the right Ascension of the Star which was to be found out.

*To find the  
right Ascen-  
sion of the  
Stars.*

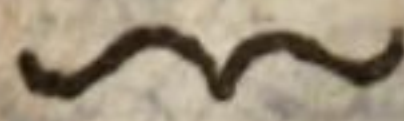
BUT by knowing the right Ascension of one Star, the right Ascensions of the rest are easiest found by the following Method; where there is no need of waiting till the Stars come to the Meridian. We only use a Telescope, in whose *Focus* there are fixed four Threads extended, two of which, as A B, C D cut one another at right Angles, and the other two E F, G H make half-right Angles with the former two, at their common Intersection O: Then the Telescope is to be directed to a Star, whose right Ascension and Declination are known.

*The right  
Ascension of  
one Star be-  
ing known,  
how from  
thence to  
find the  
right Ascen-  
sions of the  
rest.*

AND then the Telescope is to be constantly turned till the Star be seen in the Line A B, so as its appa-  
rent

Plate XVII.  
Fig. 4.



Lecture XIX.  rent diurnal Motion may be along that Line; in which Position the right Line AB will represent a Portion of that parallel Circle the Star describes, it being in a Parallel to its Plane: And because the Line CD cuts it at Right-Angles, it will represent some horary Circle. Fix then the Telescope very firm in this Situation, and mark the Time according to the Clock, when the Star, whose Ascension is known, comes to the Line CD. Then again, observe any other Star with the Telescope, which will appear to move in some Line LK that is parallel to AB; and mark likewise the Time when it comes to the horary Circle CD in Q. The Difference of Times, between the arrival of the first Star to the horary Circle, and the coming of this last to the same, converted into Degrees and Minutes of the *Æquator*, will give the Difference of their right Ascensions: And therefore if the right Ascension of one of them be found, we may from thence collect the right Ascension of the other.

BECAUSE the Angles QHO and QOH are equal, being each half a Right, QH will be equal to QO. Now if we mark the Time between the coming to the Thread OH, and its touching the Thread OQ, we shall have the Time the Star takes to describe the Portion QH of the Parallel. This Time being turned into Degrees and Minutes, will give the Number of Degrees and Minutes of the Portion QH. But the Arch of the horary great Circle is equal to this Arch QH. Now in unequal Circles the Degrees and Minutes that equal Arches contain are reciprocally as the Radii or Semidiameters of the Circles, as we shall shew hereafter. As the Radius therefore of the great Circle is to the Radius of the Parallel LK (which does not sensibly differ from the Radius of the known Parallel AB) that is, as the Radius is to the Sine of the Stars Distance from the Pole, so the Number of Degrees and Minutes in the Arch HQ of the Parallel, to the Number of Degrees and Minutes in the Arch OQ of the great Circle; which therefore will



will be known by the Rule of Proportion. But *QO* is the Difference of the Declinations of the Star which describes the Parallel *AB*, and of that which describes the Parallel *LK*; therefore from the Declination of one of these Stars being known, we can find the Declination of the other. And by this Method the right Ascensions and Declinations of most Stars may be observed.

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XIX.

THAT in unequal Circles the Numbers of similar Parts, as Degrees and Minutes, that are in Arches equal in bigness, are reciprocal to the Radii of the Circles, may be thus demonstrated. Imagine two unequal Circles, whose Center is *C*, and in them equal Arches *BE*, *AF*: Draw from the Center *CB*, *CE*, cutting from the lesser Circle the Arch *AD*. The Arches *AD* and *BE* will contain equal Numbers of Degrees and Minutes; and because *AF* and *BE* are equal, *AD* will be to *AF* as *AD* is to *BE*. But *AD* is to *BE* as *CA* is to *CB*; therefore *AD* will be to *AF* as *CA* is to *CB*. But *AD* is to *AF* as the Number of Degrees and Minutes in *AD* or in *BE* is to the Number of Degrees and Minutes in *AF*. Wherefore the Number of Degrees and Minutes in *BE* is to the Number of Degrees and Minutes in *AF*, as *CA* is to *CB*; or in a reciprocal Proportion of the Radii of the Circles. Which was to be demonstrated.

Plate XVII.

Fig. 5.

HAVING the right Ascension and Declination of a Star, its Longitude and Latitude may be found out by the Solution of a spherical Triangle. For imagine *BPQ* to pass through the Poles of the Æquator and Ecliptick; this Circle is the *Solstitial Colure*. Let *ÆQ* be the Equinoctial, *EC* the Ecliptick, whose Section with the Equinoctial is *Υ*, and let *S* be a Star, through which passes the Circle of Declination *PSF*, cutting the Equinoctial at *F*: The Arch *ΥF* is the right Ascension of the Star, and *SF* its Declination. Draw through the Pole of the Ecliptick *B* and the Star the Circle of Latitude *BSO*, meeting with the Ecliptick in *O*: Then *ΥO* will be the Longitude of the Star, and *SO*

Having the  
right Ascen-  
sion of a  
Star, and  
its Declina-  
tion to find  
its Longitude  
and Lati-  
tude.

Plate XVII.

Fig. 6.



Lecture  
XIX.

its Latitude. In the spherical Triangle  $BSP$ , we have the Side  $PS$ , which is the Complement of the Declination, and the Side  $BP$ , which is equal to the Arch that measures the Inclination of the  $\text{\AA}$ equator and the Ecliptick: Besides which, we have the Angle which is measured by the Arch  $FQ$  the Complement of the right Ascension; and therefore we have the Angle  $BPS$  its Complement to two right Angles. And therefore in the Triangle  $BPS$ , having three of its constituent Parts, we may find first the Angle  $PBS$ , whose Measure is the Arch  $OC$ , and its Complement to a Quadrant is the Arch  $\gamma O$ , which is the Longitude of the Star. We can likewise from the same Things given find the Arch  $BS$ , whose Complement to a Quadrant is  $SO$ , the Latitude of the Star. After the same Method, if the Longitude and Latitude of a Star be known, we may from thence find its right Ascension and Declination.

By comparing the Places of the fixed Stars, as they were deliver'd to us by the Antients, with what they now obtain, we find that their Latitudes are much the same they were formerly; but their Longitudes or Distances from the first of  $\gamma$  have been found to increase continually: Not that the Stars have a real progressive Motion; but because the Equinoctial Points have a Motion backwards, and the Longitudes are computed from them. The Longitude of any fixed Star observed by the antient Astronomers, compared with the Longitude it has at present, shews the Quantity of this Regression of the Equinoctial Points to be about one Degree in 72 Years.

By the Method we have shewed, the Longitudes and Latitudes of the fixed Stars are found, and they and their Places are ranked in a Catalogue; which being once established, the Places of the Planets and Comets are easily known by Observation and Computation. For if the Distances of any Planet or Comet, from two fixed Stars of known Longitude and Latitude, be taken by Observation, we may by that Means determine the Longitude and Latitude



tude of the Planet or Comet in the following Manner: Lecture XIX.

LET EF be a Portion of the Ecliptick, whose Pole is B; and let A and C be two Stars, whose Longitudes and Latitudes are known, and P a Planet, whose Distances from the same Stars are known by Observation. In the Triangle ABC, having AB and CB the Complements of the Latitudes of the two Stars, and the Angle ABC, whose Measure is the Arch EF, the Difference of Longitude of the two Stars; from thence we may find AC the Distance of the Stars, and the Angle BCA. Again, in the Triangle APC we have all the Sides, from which we may find the Angle PCA; which being subtracted from BCA, will leave the Angle BCP. Lastly, in the Triangle BCP, we have the Sides BC, CP, and the Angle PCB; from which we can find the Angle PBC, whose Measure is OF the Difference of Longitude of the Star C and the Planet. We can also find the Arch PB the Complement of the Latitude of the Planet.

AFTER the same Method, if we have the Distances of a Planet from two fixed Stars, whose right Ascensions and Declinations are known, we may find out the right Ascension and Declination of that Planet.





## LECTURE XX.

*Of the Twilight, and of the Refraction  
of the Stars.*

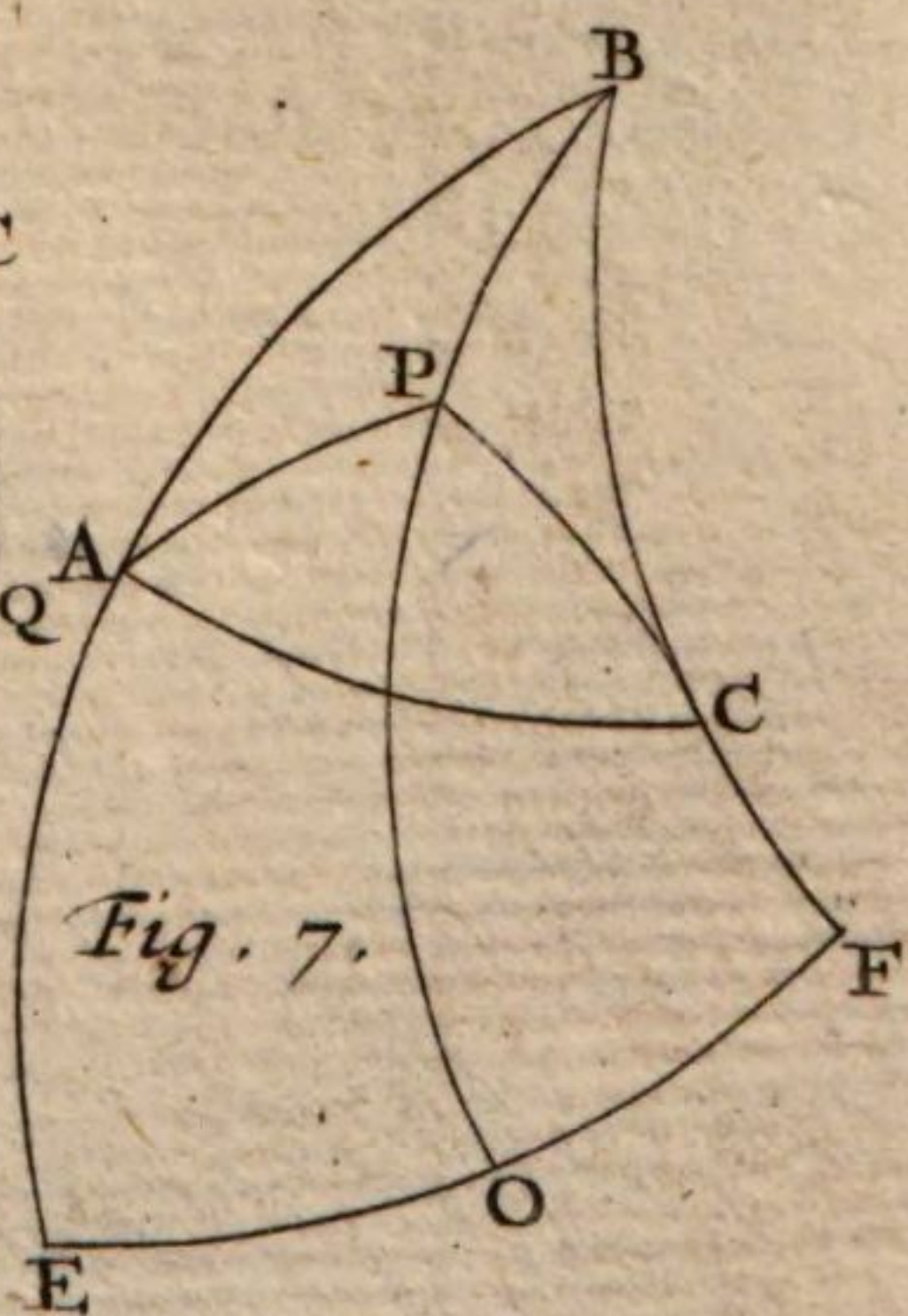
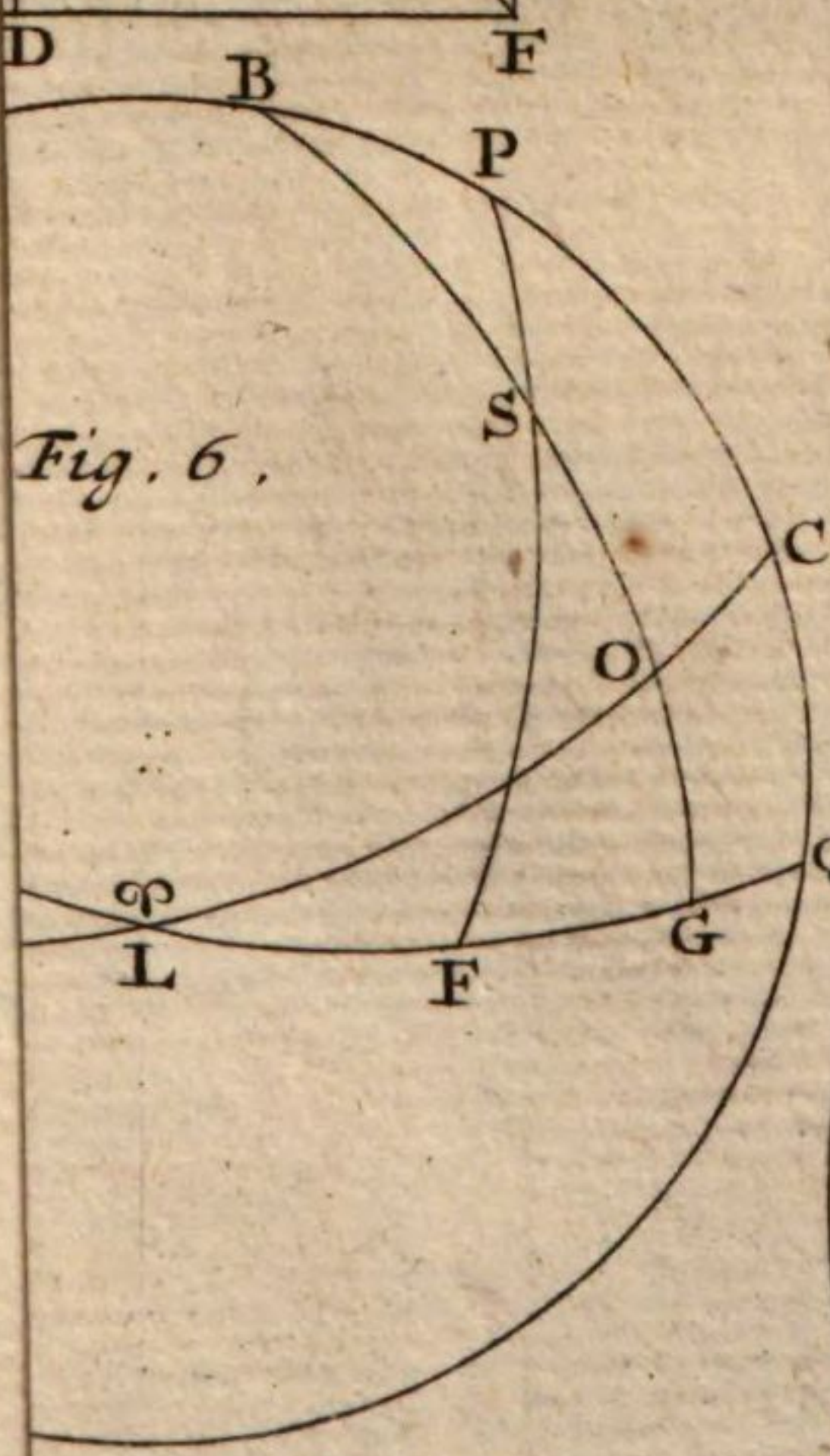
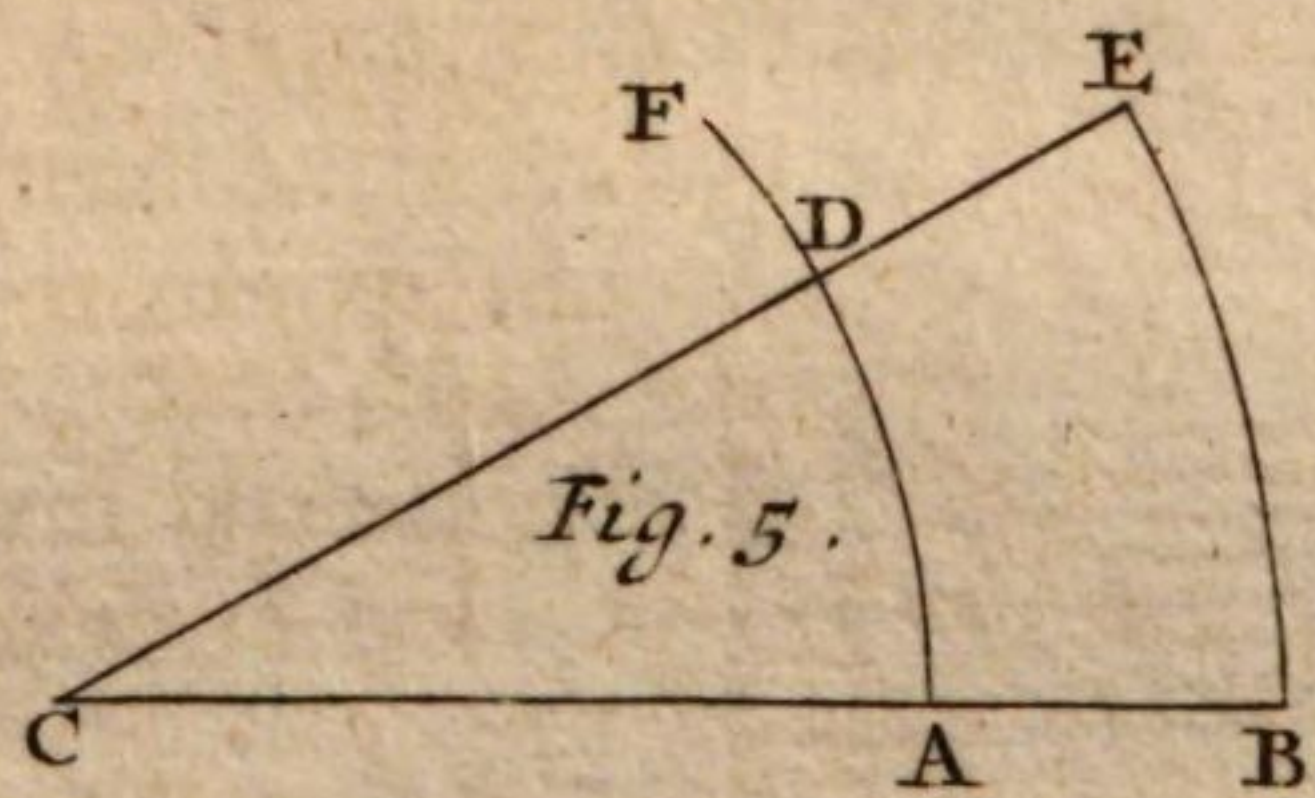
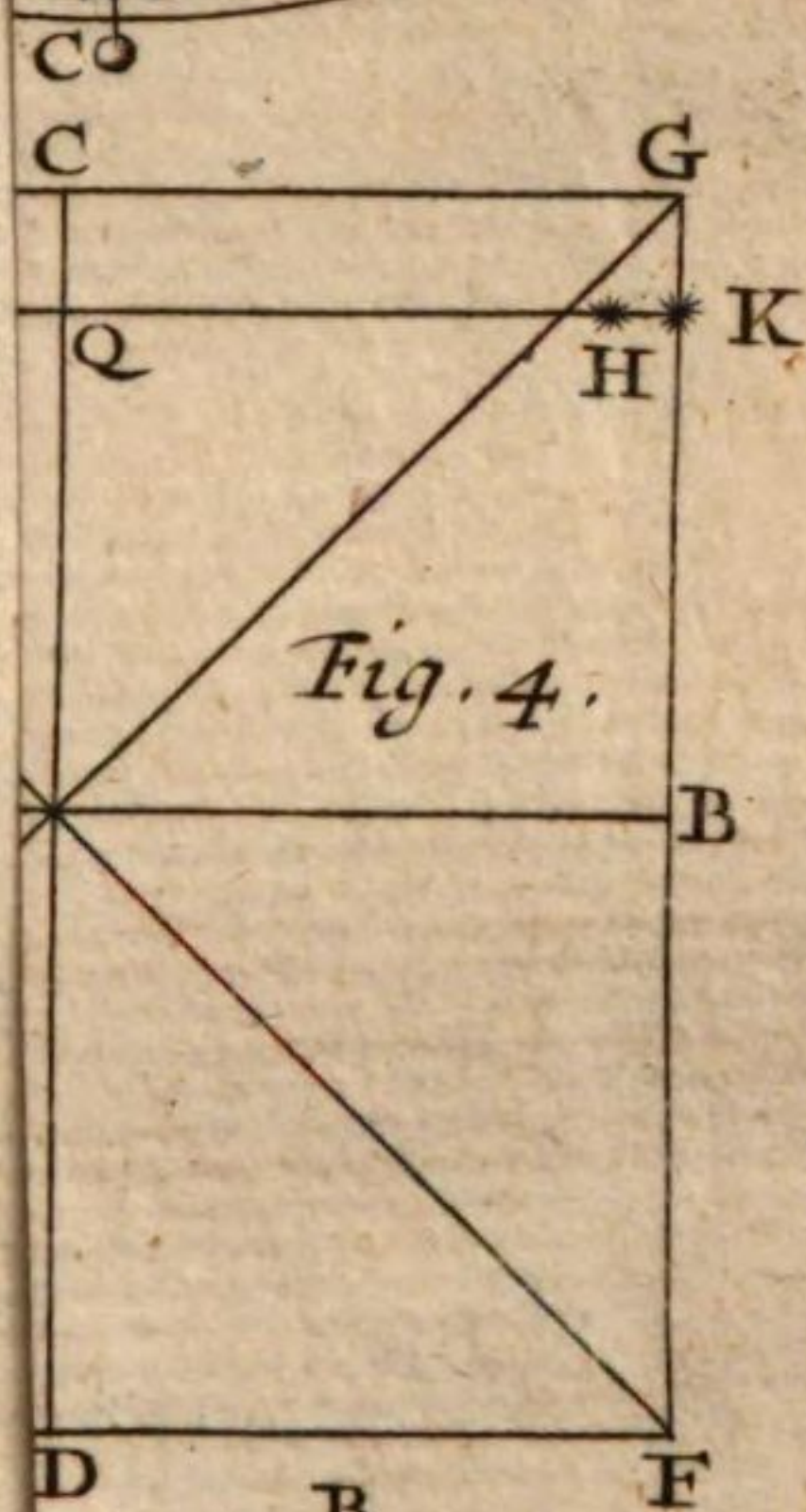
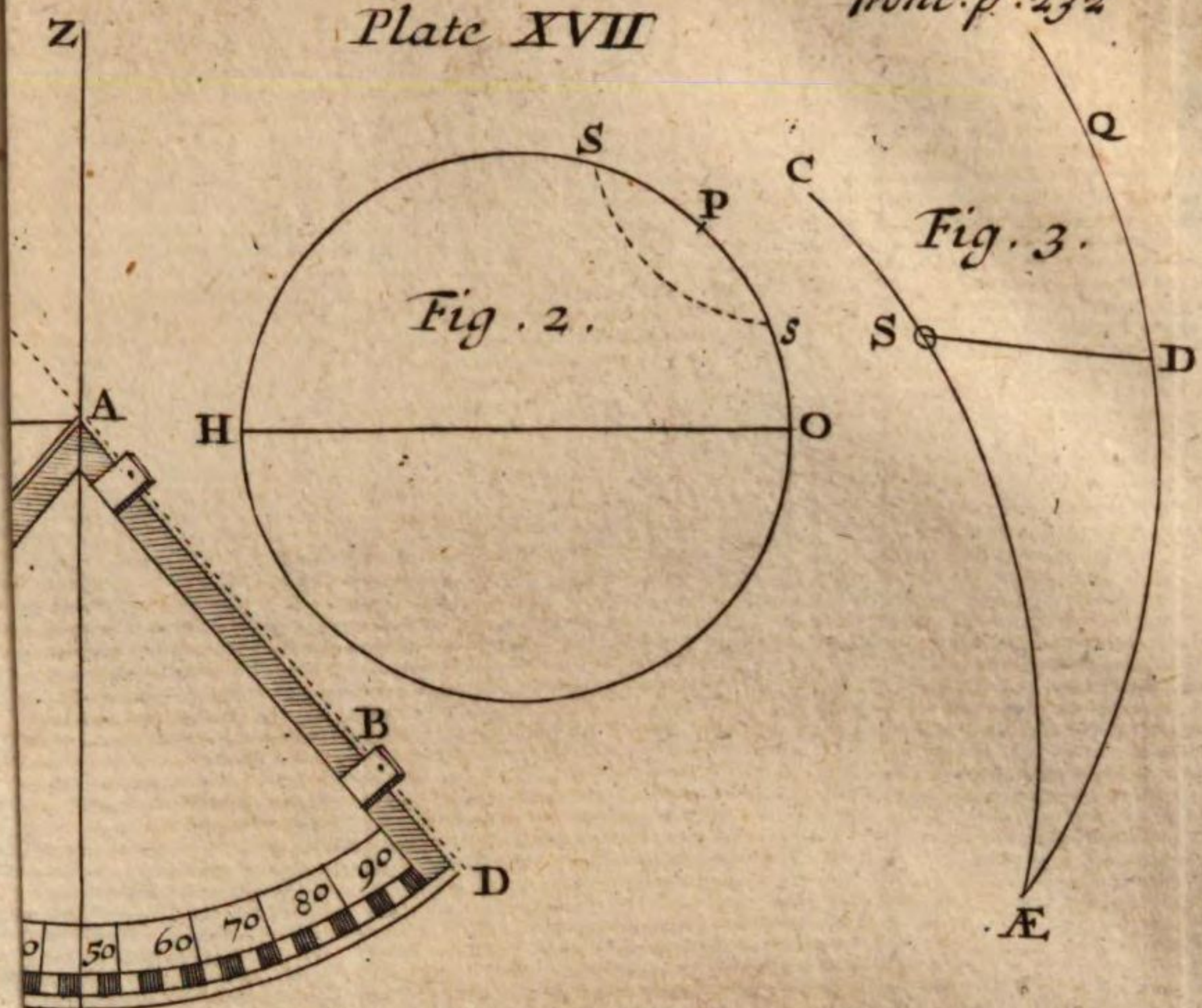
The Air  
makes the  
Firmament  
lucid.



BESIDES other innumerable Conveniences which we receive from the *Atmosphere*, we have this great Advantage, that while the Sun shines, it makes the Face of the Heavens or Firmament to appear lucid and bright; for if no *Atmosphere* surrounded and involved the Earth, only that Part of the Heavens would appear to shine in which the Sun was placed: And a Spectator, if he should turn his Back to the Sun, would immediately perceive it as dark as Night; and even in the Day-time, while the Sun shined, the least Stars would be seen shining, as they do now in the clearest Night; since in that Case there would be no Substance to reflect the Rays of the Sun to our Eyes, and all the Rays which do not fall upon the Surface of the Earth, passing by us, would either illuminate the Planets and Stars, or spreading themselves out into infinite Space, would never be reflected back to us.

BUT since there is an *Atmosphere* covering the Earth, which is strongly illuminated by the Sun, it reflects the Light back upon us, and makes the whole Heavens to shine; and that so strongly, that by reason of its Splendor, it obscures the faint Light of the Stars, and renders them invisible.











IF there were no *Atmosphere*, the Sun immediately before his setting, would shine as briskly as at Noon; but in a Moment, as soon as he is set, we should have the Face of the Earth in as great Darkness as it would be at Midnight: So quick a Change, and so sudden a passing from the greatest Light to the greatest Darkness, would be very inconvenient to the Inhabitants of the Earth. But by means of the *Atmosphere* it happens, that tho' after Sun-setting we receive no direct Light from the Sun, yet we enjoy its reflected Light for some Time; so that the Darkness of the Night comes not suddenly, but by degrees. For after the Earth by its Revolution round its Axis has withdrawn us from the Sight of the Sun; the *Atmosphere* which is higher than we are, will still be illuminated by the Sun; so that for a while the whole Heavens will have some of his Light imparted to it. But as the Sun goes still lower under the Horizon, the less is the Air illustrated by him: So that when he is got as far as 18 Degrees lower than the Horizon, he no longer enlightens our *Atmosphere*, and then all that Part thereof that is over us becomes dark.

So likewise in the Morning, as soon as the Sun comes within 18 Degrees of the Horizon, he begins again to enlighten the *Atmosphere*, and to diffuse his Light through the Heavens: So that its Brightness does still increase, till the Sun rises and makes full Day. This small Illumination of the *Atmosphere*, and state of the Heavens between Day and Night, is what we call the *Twilight*, which is observed in the Morning before the Sun's rising, and at Night after his setting; in *Latin* it is named *Crepusculum*.

To make this plainer, imagine the Circle ADL on the Surface of the Earth, in the Plane of the vertical Circle in which the Sun is when under the Horizon. Let there likewise be another concentric Circle CBM in the same Plane, including that Portion of the Air that reflects the Sun's Beams: And suppose the Eye to be on the Earth's



Lecture XX.  Earth's Surface at A, whose sensible Horizon is AN. Since no Line can be drawn to A between the Tangent AN and the Periphery AD, by the 16th of the *Third Element*; it is plain, that when the Sun is under the Horizon, no direct Rays can come to the Eye at A: But the Sun being in the Line CG, a Line may be drawn from him to C, so that the Particle C may be illuminated by the direct Rays of the Sun; which Particles may reflect those Rays to A, where they may enter the Eye of the Spectator: And by this Means the Beams of the Sun's Light illuminating an innumerable Multitude of Particles, may by them be reflected to the Spectator in A. Let the Tangent AB meet with the Surface of the Orb of Air that reflects the Light in B; and from B draw BD, touching the Circle ADL in D, and let the Sun be in the Line BD at S: Then the Ray SB will be reflected into BA, and will enter the Eye, because of the Angle of Incidence DBE being equal to the Angle of Reflection ABE: And that will be the first Ray that reacheth the Eye in the Morning, and then the Dawning begins; or the last which falls upon the Eye at Night, when the *Twilight* ends. For when the Sun goes lower down, the Particles at B can be no longer illuminated.

Another  
Cause of the  
Twilight.

THE Reflection of the *Atmosphere* does not seem to be the only Cause of the *Twilight*; but there is an *Ætherial Air*, or *Atmosphere*, likewise round the Sun, which shines after the Body of the Sun is set: This Orb of the Sun's *Atmosphere* rising sooner, and setting later than the Sun itself, shines out at Mornings and Nights in a circular Figure, it being a Segment of the Sun's *Atmosphere* cut by the Horizon; and its Light is quite of another sort, than that which is made by the Reflection of our *Atmosphere*. But the Duration of the *Twilight* that arises from the Sun's *Atmosphere*, is shorter much than that made by the Reflection of the *Earth's Atmosphere*, which does not end till the Sun comes to be 18 Degrees below the Horizon,



zon, or thereabouts. But there can be no certain Bounds fixed for the Beginnings and Endings of the *Twilights*; for their Lengths depend on the Quantity of Matter in the Air which is able to reflect Light, and on the Height of the *Atmosphere*. In the *Winter* the Air, being condensed by the Cold, is low; and on that Account the *Twilights* are sooner over. In the *Summer* the Air is rarify'd by Heat, and therefore being higher, remains longer illuminated by the Sun, so that the *Twilights* last the longer: Also the Duration of the *Twilight* is shorter in the Morning than at Night. We generally reckon that the *Twilight* begins or ends, when in the Morning the Stars of the sixth Magnitude disappear, or in the Evening when they first come to be seen; the Light of the Air before that rendering them invisible. *Ricciolus* observed at *Bononia*, that the Morning *Twilight*, about the Time of the *Equinocties*, lasted an Hour and 47 Minutes; but in the Evening two Hours, and did not end till the Sun was 20 Degrees under the Horizon: But in *Summer* the Morning *Twilight* was three Hours and 40 Minutes long; the Evening *Twilight* scarcely ending till Midnight.

HENCE if we have the Time of Beginning of the *Twilight* in the Morning, or the End of it at Night, we may find the Height of the Air that reflects the Light; for then the *Twilight* ends, when a Ray of Light from the Sun touches the Globe of the Earth, and is by the highest Air reflected to our Eyes: For having the Time, we can find the Depression of the Sun below the Horizon, and from thence the Height of the Air. For let *SB* be a Ray of Light touching the Earth, which is reflected by a Particle of Air in its highest Region, in the Horizontal Line *AB*; the Angle *SBN* is the Measure of the Depression of the Sun below the Horizon: And because *AB* is also a Tangent, the Angle *AED* at the Center is equal to the Angle *SBN*; and its Half, that is, the Angle *AEB*, is equal to half *SBN*, or half the Depression of the Sun. Suppose the Depres-  
sion

*The Height  
of the At-  
mosphere  
measur'd by  
an Observa-  
tion of the  
Twilight.*



Lecture XX.  sion of the Sun, at the Beginning or End of *Twilight*, be 18 Degrees; then the Angle A E B will be 9 Degrees, which would be true, did the Ray S B pass thro' the *Atmosphere* without Refraction: But because it is refracted and bent towards H, we must diminish the Angle A E B by a Quantity equal to the Horizontal Refraction, which is above half a Degree: And therefore the true Measure of the Angle A E B is  $8\frac{1}{2}$  Degrees. Moreover, A E is to B H as the Radius is to the Excess of the Secant of the Angle A E B above the Radius, that is as 100000 is to 1110. Therefore if the Semidiameter of the Earth be in round Numbers 4000 Miles, B H the Height of the *Atmosphere*, which reflects the Sun's Rays, will be about 44 Miles; for as 100000 is to 1110, so is 4000 to 44.

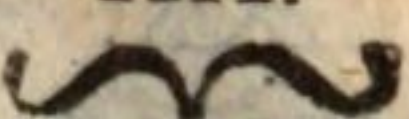
Under the *Æquator* the Time of the *Twilight* is short. IN a right Position of the Sphere the *Twilights* are quickly over; because the Sun descends constantly nearer in a Perpendicular; but in an oblique Sphere they last longer, the Sun descending obliquely; and the more oblique the Sphere is, that is, the greater the Latitude of the Place is, so much longer last the *Twilights*: So that all they who are in above 48 Degrees Latitude, in the *Summer*, near the Solstices, have their *Atmosphere* illuminated the whole Night, and the *Twilight* lasts till the Sun-rising, without any compleat Darkness.

Under the Poles they last some Months. IN a Parallel Sphere the *Twilight* lasts for several Months; so that the Inhabitants have either the direct or reflect Light of the Sun for almost all the Year.

The Circle terminating *Twilight*. IF below the Horizon you conceive a Circle to be drawn parallel to the Horizon, and at a Distance from it, equal to the Depression of the Sun at the end of the *Twilight*: This lesser Circle is called the *Circle which terminates the Twilights*; for whenever the Sun by its apparent diurnal Motion reaches this Parallel, the Morning *Twilight* begins, or the Evening ends, in whatever Parallel of the *Æquator* the Sun is.

IN



IN the Figure let HQO be the Horizon, Lecture  
 V a X the Circle parallel to it, terminating the XX.  
*Twilight*, the Circle HZO the Meridian,  $\text{Æ} Q a$    
 the  $\text{Æ}$ quator. It is manifest that the more ob- <sup>The Arches</sup>  
 lique the  $\text{Æ}$ quator is to the Horizon, so much the <sup>of the Cre-</sup>  
 greater are the Arches of the  $\text{Æ}$ quator and its <sup>puscles or</sup>  
 Parallels, intercepted between the Horizon and <sup>Twilight.</sup>  
 the terminating Circle V a X. The Arches QR,  
 d a, Ce, G b, K l, are called the Arches of the  
*Twilights*, because they determine their Duration:  
 And as each Arch has a bigger or less Proportion <sup>Plate XIX.</sup>  
 to its Circle, so will the *Twilight*, when the Sun is <sup>Fig. 2.</sup>  
 in that Parallel, be longer or shorter. In the Cir-  
 cle bounding the *Crepuscles* take any Point a, thro'  
 which passes a Parallel to the  $\text{Æ}$ quator d a; and  
 through a imagine a great Circle to be drawn, as  
 M a N, touching the Circle of perpetual Appa-  
 rition: And since the Horizon likewise touches the  
 same Circle, these two Circles will make equal  
 Angles with the  $\text{Æ}$ quator and its Parallels; for  
 the Measure of each Angle is the Distance of the  
 Parallel from its great Circle. So likewise all the  
 Arches of the  $\text{Æ}$ quator and its Parallels, between  
 the Horizon and the Circle M a N are similar, by  
*Prop. 13, Book II. Theodosius's Sphericks.* This  
 Circle M a N will either cut the bounding Circle  
 V a X in two Points, or touch it in one. Let it  
 first cut it in two Points a and b; and therefore  
 the Arches of the Parallels d a, G b are similar:  
 Wherefore when the Sun by its diurnal Motion  
 describes these two Parallels, the *Twilights* are  
 equal; but while he describes any intermediate  
 Parallel as Ce, the Time of the *Twilight* is shor-  
 ter; for in this Case C m the Arch of *Twilight* is  
 less than Ce, which is similar to the Arch d a  
 or G b, and Ce and d a are described by the Sun  
 in equal Times. But when the Sun is in Parallels  
 that are at a greater Distance from the  $\text{Æ}$ quator  
 than G b, the *Twilights* last longer; for the *Twilight*  
 Arch l K is greater than q K, which is described by  
 the Sun in the same Time as the Arch of the *Cre-*  
*puscle* G b.

WHILE



Lecture  
XX.

The difference  
of Duration of the  
Twilights.

WHILE the Sun is in Parallels that are towards the elevated Pole, the *Twilights* do constantly grow longer, according as those Parallels approach the Poles: For the *Twilight* Arch  $op$  is longer in being described than  $QR$ , and  $YU$  the same way is longer than  $op$ . But if the Sun describe the Parallel  $Sz$ , it never will meet with the bounding Circle, and then the *Twilight* lasts the whole Night long.

HENCE arises a great Difference between the Increase of the *Twilight* and its Decrease, and the Increase and Decrease of Days and Nights. For while the Sun moves from the Beginning of  $\text{♊}$  to the first of *Capricorn*, all that Time the Days constantly decrease, and the Nights increase: But in the *Twilight* it is otherwise; for though the *Twilight* and Days are at the longest when the Sun is in the first Degree of  $\text{♊}$ , and then they both decrease together; yet the Times of *Twilight* do not continually decrease till the Sun comes to  $\text{♋}$ , but there is a certain Point between  $\text{♊}$  and  $\text{♋}$ , to which when the Sun arrives, we have the shortest *Twilight*. From thence the *Twilights* will begin to increase again, and there will be one Arch of *Twilight*, similar to that when the Sun is in the *Æquator*, before he reaches  $\text{♋}$ : And if the Sun should go further South even beyond the Tropick, the *Twilights* would still increase, although the Days decreased. And although the Days from the Beginning of the Sun's Entry into  $\text{♋}$  do constantly increase, yet the *Twilights* grow shorter till the Sun comes to a Point between  $\text{♋}$  and  $\text{♌}$ , in which again we have the shortest *Twilight*: This appears plain by what we are here to demonstrate in the next Place.

Plate XIX,  
Fig. 3.

2dly, LET the Circle  $MAN$  touch the bounding Circle in one Point, which suppose to be  $a$ , through which draw the Parallel to the *Æquator*  $da$ ; I say, that when the Sun is in this Parallel, the *Twilight* will be the shortest of all. For because the Arches of the Parallels intercepted between the Horizon and the Circle  $MAN$  are all similar, they



they will be described by the Sun in equal Times: Lecture  
 But because the *Twilight* Arches  $ce$  and  $gb$  are XX.  
 greater than  $cm$  or  $gi$ , the Sun will be longer in  
 moving thro' the Arch  $ce$  than  $cm$ , and through  
 the Arch  $gb$  than  $gi$ ; that is longer than in de-  
 scribing the Arch  $da$ , which Arch therefore is the  
 shortest *Twilight*.

THE Distance of that Parallel from the Equator, in which is the shortest *Twilight*, is thus in-  
 vestigated. Because the Circle  $MaN$  and the *The Time of*  
 Horizon  $HO$  touch the same Parallel, which is *the shortest*  
 the Circle of perpetual Apparition, they will both *Twilight*  
 be equally inclined to the  $\text{\AA}$ equator: And there- *investigated.*  
 fore the Angle  $anT$  of the  $\text{\AA}$ equator, and the Cir-  
 cle  $MaN$ , is equal to the Angle  $FQd$  of the  
 $\text{\AA}$ equator and the Horizon. Thro' the Zenith  $Z$   
 and the Point  $a$ , draw the vertical Circle  $ZYa$ ,  
 cutting the  $\text{\AA}$ equator in the Point  $T$ . The Sphe-  
 rical Triangles  $anT$ ,  $TQY$ , are mutually equi-  
 angular to each other, because the Angles at  $a$  and  
 $Y$  are right; and we have shewed that the Angles  
 at  $Q$  and  $n$  are equal; also the Angles at  $T$  are  
 equal, being vertical to each other: These Tri-  
 angles then being equiangular, are also equilateral;  
 and therefore  $Ta$  will be equal to  $TY$ , or to half  
 the Distance of the bounding Circle from the Ho-  
 rizon: Moreover,  $an$  is equal to  $Qd$ , by 13 *Prop.*  
*Book II. Theod.* for  $FR$  and  $da$  are parallel, and  
 therefore  $dQ$  is equal to  $QY$ .

IN the Spherical Triangle  $TQY$  rectangular  
 at  $Y$ , we have the Side  $TY$  half the Distance of  
 the bounding Circle from the Horizon; as also  
 the Angle  $YQT$  equal to  $FQd$ , which mea-  
 sures the Complement of the Latitude of the Place;  
 wherefore we can find  $QY$ , and  $Qd$ , which is  
 equal to it. From the Point  $d$  to the  $\text{\AA}$ equator  
 draw the Circle of Declination  $dF$ ; and in the  
 Spherical Triangle  $dQF$ , we have  $dQ$  and the  
 Angle  $Q$ , by which we can find the Arch  $dF$ , the  
 Declination of the Parallel of the least *Twilight*  
 from the  $\text{\AA}$ equator, which was to be found.

THIS



Lecture  
XX.

The same  
Problem  
solved by a  
single Ana-  
logy.

The Dura-  
tion of Twi-  
light deter-  
mined.

Refraction  
by the At-  
mosphere.

THIS Problem might have been solved by one single Analogy. For in the Triangle  $TQY$ , the Radius : Tang.  $TY$  :: Co-tang.  $Q$  : Sin.  $QY$  or to the Sin. of  $dQ$ : But the Sin. of  $Q$  : Co-sin. of  $Q$  :: Rad. : Co-tang.  $Q$ . Therefore by the Rules of the 5th Element, the Rad. multiplied by the Sin. of  $Q$ , will be to the Tang. of  $TY$  into the Co-sin. of  $Q$ , as the Radius is to the Sin. of  $Qd$ : But in the Right-angled Triangle  $QdF$ , Radius is to the Sine of  $Qd$  as the Sine of the Angle  $Q$  to the Sine  $dF$ ; wherefore Rad.  $\times$  Sine  $Q$  will be to Tang. of  $TY \times$  Co-sine of  $Q$ , as the Sine of  $Q$  to Sine of  $dF$ ; and thence, *ex æquo*, it will be as Radius to Tang. of  $TY$ , so Co-sine of  $Q$  or the Sine of the Latitude, to the Sine of the Distance of the Parallel from the  $\text{\AA}$ equator. Having the Declination of the Sun, the Time of the Beginning of the Morning *Twilight*, which we call Break of Day, or the End of the Evening *Twilight*, is thus to be found. Let  $op$  be the Parallel of the Sun, meeting with the bounding Circle in  $p$ ; and draw through the Pole the Circle of Declination  $Pp$ . In the spherical Triangle  $PZp$  we have all the Sides, for  $ZP$  is the Complement of the Latitude,  $Pp$  the Complement of the Sun's Declination, and  $Zp$  equal to the Sum of a Quadrant, and the Distance of the bounding Circle from the Horizon  $= Zl + lp$ . From which we can find the Angle  $ZPp$ , and its Complement to two Rights  $pPV$ : And the Arch of the  $\text{\AA}$ equator, measuring this Angle, being converted into Time, will shew the Beginning or End of *Twilight*.

THE TERRESTRIAL ATMOSPHERE, by reflecting the Sun's Beams, not only produces the Morning and Evening *Twilight*, but it also bends and refracts the Rays of the Sun, and all the Stars which fall on it, and changes their Directions by propagating the Light in other Lines, making the apparent Places of the Stars different from their true Places.

By manifold Experiments, we find that the Rays of a luminous Body, even of any visible Object,



ject, when they fall upon a *Medium* or Diaphanous Body, as Air or Water, of a different Density from that from whence they first proceeded; do not afterwards go directly in the same strait Lines, but are broken or bended, and propagated as if they had proceeded from another Point than they really did. And if the *Medium* on which the Rays fall be denser than the first, they are bent towards a Line perpendicular to that Surface whereon they fall, at the Point of Incidence; but if it be a *Rarer Medium*, in their bending they recede from the Perpendicular.

WE observe in Nature many Effects of Refraction. A Staff, whose one Part is immersed in Water and the other in the Air, appears broken; and that Part which is in Water appears higher than it really is. All the Stars by Refraction appear higher or nearer to our Vertex than they would be, were there no Air; so that the Light might arrive to us without Refraction.

LET ZV be a Quadrant of a Vertical Circle in the Heavens, described from the Center of the Earth T; under which is AB, a Quadrant of a Circle on the Surface of the Earth, and GH a Quadrant on the Surface of the *Atmosphere*: And let S be any Star from which proceeds the Beam of Light SE, falling on the Surface of the Air in E. Now, since this Ray comes from the Etherial Air much rarer than ours, or rather from a perfect Void, and falls on our *Atmosphere*, which is dense in Comparison of it; in E it will be refracted towards the Perpendicular: And because the upper Air is rarer than that which is nearer the Earth, and grows still denser the nearer it is to us, this Ray of Light, as it proceeds, will constantly be refracted and bended; so that it will arrive at our Eye in the curve Line EA: Suppose the right Line AF to touch this Circle in A; according to the Direction AF, the Ray of Light will enter the Eye at A. And because all Objects are seen in the Line according to whose Direction the Rays enter the Eye, and strike upon  
R the

Plate XIX.  
Fig. 4.



Lecture the *Sensorium*; the Object will appear in the Line  
XX. A F, that is, in the Heavens at Q; which is nearer

 to our Vertex than the Star really is. And it may even happen, that a Star which is below the Hori-

zon may be seen above it. This Refraction is also the Cause why the two great Luminaries the Sun and Moon, when one of them is above the Hori-  
zon and the other below it, both may appear above the Horizon; so that the Moon has been observed eclipsed, when she was below the Horizon and the Sun above it.

By Refrac-  
tion an E-  
clipse of the  
Moon may  
be seen when  
she is under  
the Horizon.

Where the  
Refraction  
is greatest;  
where the  
least.

All the Stars  
at equal  
Heights  
have equal  
Refractions.

A STAR in the Vertex or Zenith has no Refrac-  
tion, for a perpendicular Ray goes strait on; but the more obliquely the Ray falls upon the Surface of the Air, so much the greater is the Refraction; so that the horizontal Refraction is the greatest of all. And a Star that is above 50 Degrees high has scarcely a sensible Refraction. In equal Altitudes the Refractions are equal: And therefore the Sun, Moon, and fixed Stars, at the same apparent Height, have all the same Degree of Refraction; though the noble *Tycho Brahe*, the Restorer of *Astronomy*, and first Observer of Refractions, thought otherwise. Hence, if the Refractions of the fixed Stars are known, we shall know likewise the Refractions of the Sun, Moon, and Planets: And it is easier to find by Observation the Refraction of a fixed Star than that of the Sun and Moon: For the Parallaxes of these Bodies not being exactly known, the Observations about their Refractions will be doubtful; but the fixed Stars having no Parallax, all the Difference between their true and observed Places is wholly owing to Refraction.

The Method  
of observing  
the Refrac-  
tion.

Plate XIX.  
Fig. 5.

THOSE fixed Stars, that rise higher above the Ho-  
rizon than 50 Degrees, have their Declinations, right  
Ascensions, Longitudes and Latitudes accurately  
enough known; for in so great an Altitude, the Re-  
fraction is next to nothing. Now these being known,  
we find the Refractions near the Horizon by the  
following Method. Let OPZH be the Meridian,  
HO the Horizon,  $\text{ÆQ}$  the  $\text{Æquator}$ , P the Pole,  
and





and the Vertex  $Z$ . Let  $A$  be a *Star* whose Refraction is to be found, and let  $ZD$  be a vertical Circle passing thro' the *Star*, whose apparent Place suppose to be  $C$ ; the Arch  $AC$  is the Refraction. Let the apparent Distance of the *Star* from the Vertex be observed, that is the Arch  $ZC$ : And at the Time of the Observation take the Altitude of another *Star*, which is so high that it is not liable to Refraction, with which find out the Moment of Time the Observation was made; which may also be known by a good Pendulum Clock: By this Time, and the right Ascension of the Sun, we shall find the Point of the  $\mathcal{A}$ equator, which then culminates, or is in the Meridian, that is, the Point  $\mathcal{A}$ . But we have also the right Ascension of the *Star*, that is, the Point  $B$ , where the Circle of Declination, passing thro' the *Star*, meets the  $\mathcal{A}$ equator; and consequently, the Arch  $\mathcal{A}B$  will be known; which is the Measure of the Angle  $ZPA$ . Therefore, in the spherical Triangle  $ZPA$ , having  $ZP$ , the Distance of the Pole from the Vertex, and  $PA$ , the Complement of the *Star's* Declination, as also the Angle  $ZPA$ , we find out by *Trigonometry* the Side  $ZA$ , the true Distance of the *Star* from the Vertex; from which subtract  $ZC$ , the apparent Distance known by the Observation, and there will remain  $AC$ , the Refraction of the *Star*, which was to be found.

THE Refraction may likewise be found by observing the Azimuth of a *Star*, or the Arch of the Horizon between the Meridian and the Vertical Circle passing through the *Star*, that is, the Arch  $DO$ ; for that Arch measures the Angle  $PZA$ , from which, and the Sides  $PZ$ ,  $PA$ , we may find  $ZA$ , the true Distance of the *Star* from the Vertex; from which subtract  $ZC$ , the observed Distance, and we shall have  $CA$ , the Refraction required.

THE Azimuth of any *Star* is best observed, by drawing on the Plane of the Horizon the Meridian Line  $AE$ ; upon which, erect the Perpendicular  $CA$ ; which is easily perform'd by a Line and a Plummets: Then take another Thread with a Weight, as  $BD$ ,

*Another Method for finding the Refraction.*

*The Method of observing the Azimuth of a Star.*  
Plate XIX.  
Fig. 6.



Lecture XX. and hang it so that the Body of the *Star* may be covered by the two Threads CA, DB, and then the *Star* will be in the Plane of a Vertical Circle, in which Plane the Threads do likewise stand: Mark then the Point B in the Plane of the Horizon, and in the Meridian Line, the Point A, upon which is erected the Thread AC: And taking in the Meridian Line any Point E, draw AB, BE; then, by the Help of a Scale of equal Parts, measure the three Sides of the Triangle BAE, from which by *Trigonometry* we shall find the Angle BAE, which is the Azimuth that was to be found.

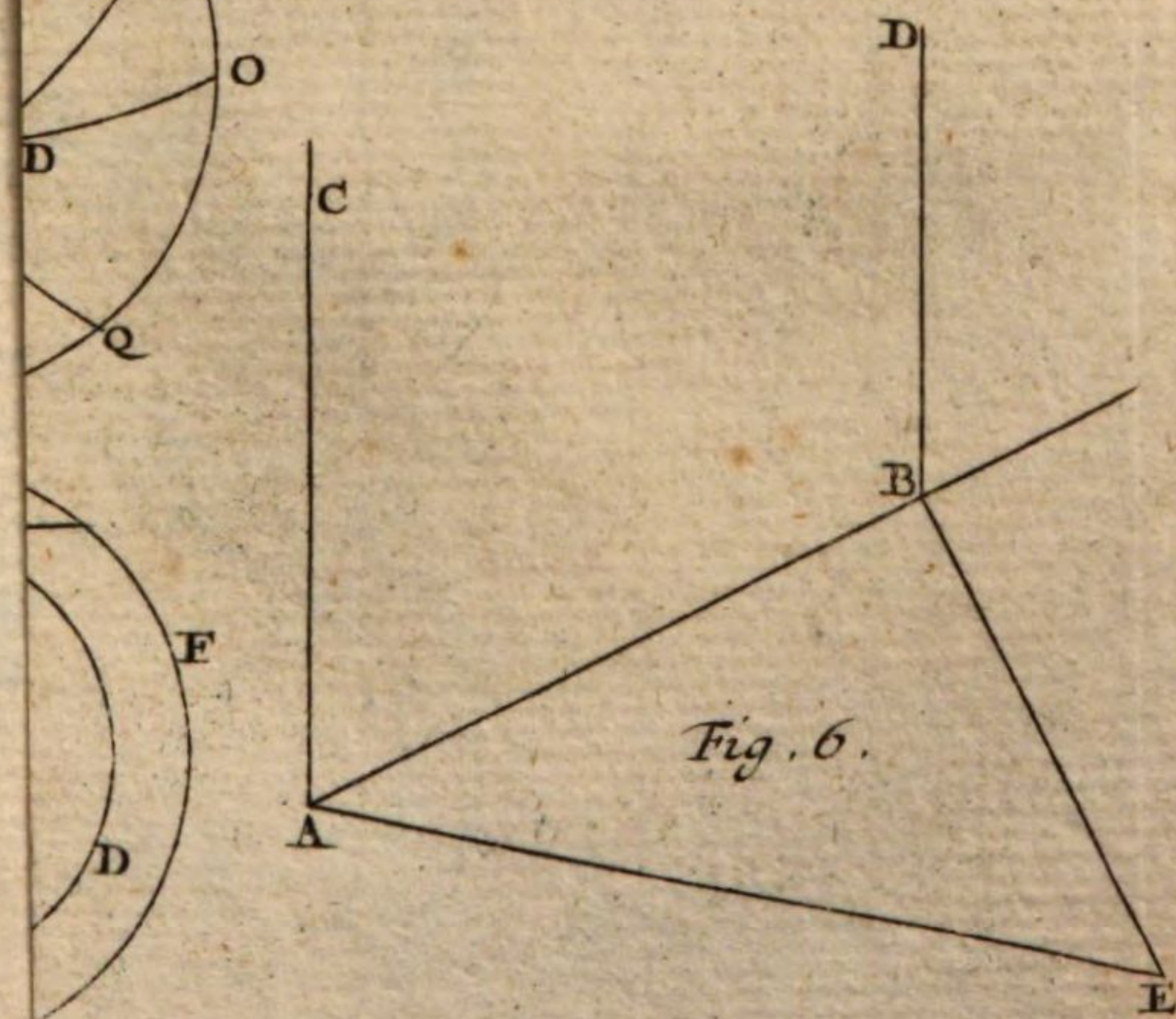
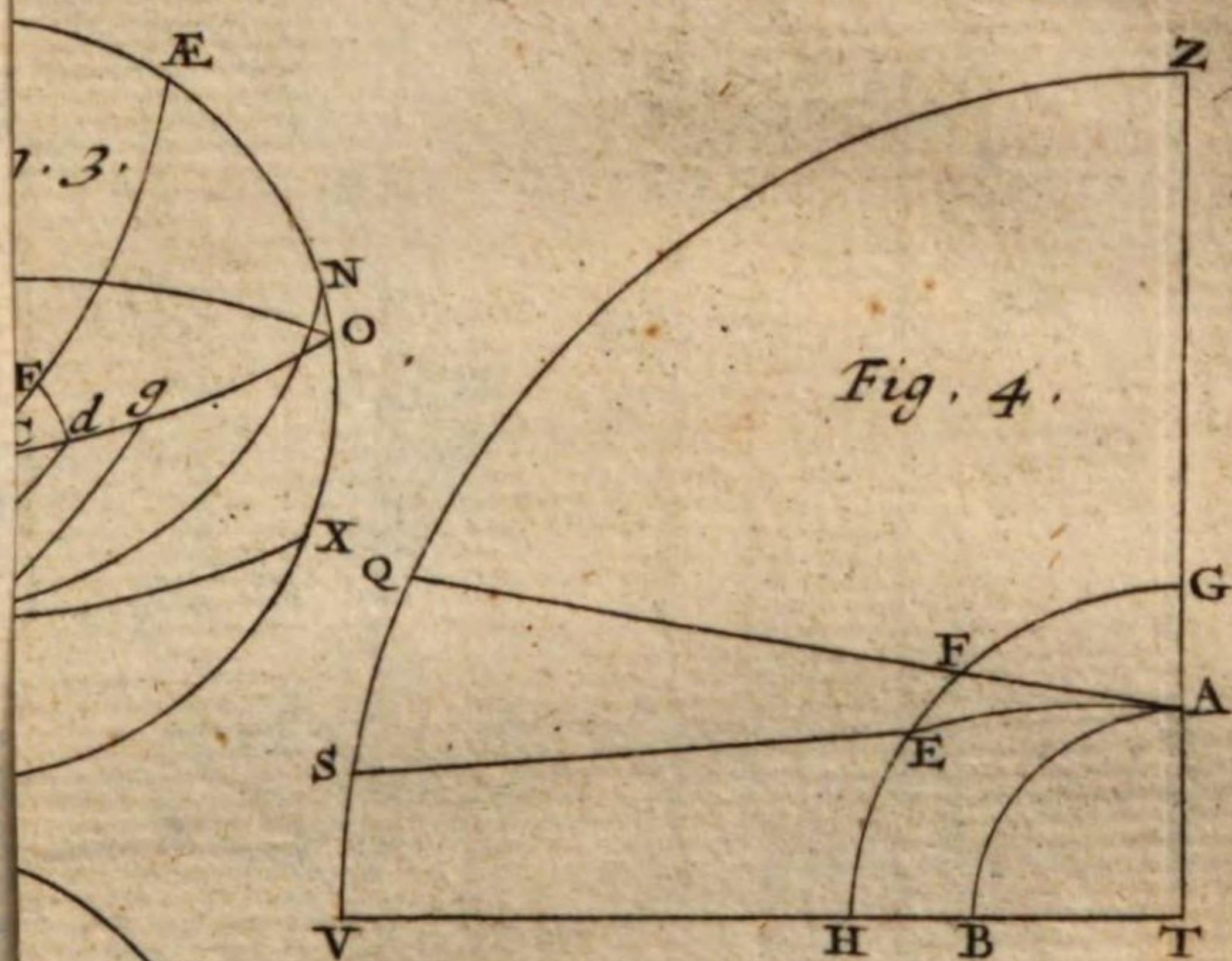
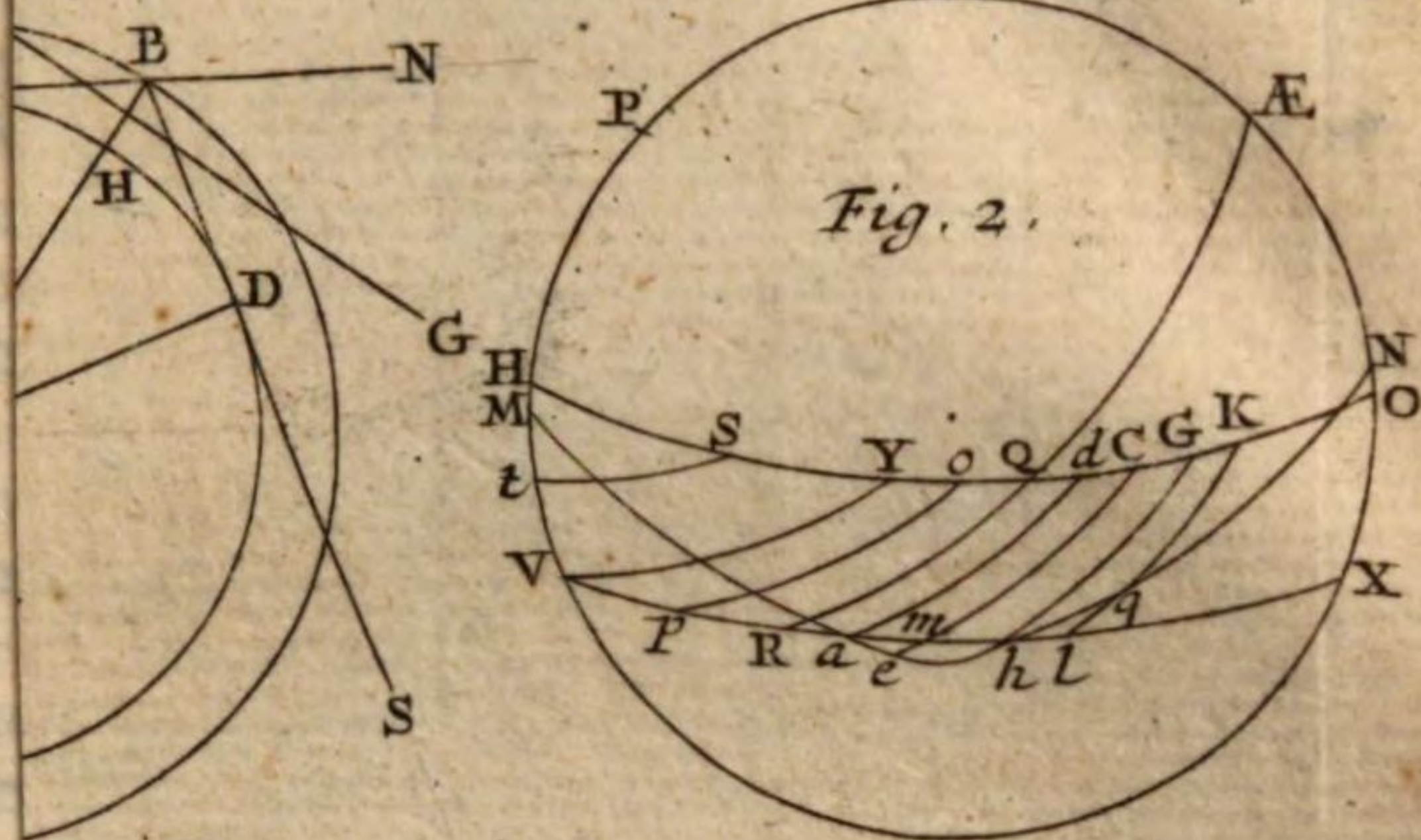
FROM Refraction, the Reason is plain why the Sun and Moon near the Horizon appear of an oval Figure; for their inferior Limbs are more refracted, and raised higher than the superior Limbs are; and therefore, these two Limbs will seem nearer to each other, and the Breadth of the Bodies contracted, while both Ends of the horizontal Diameter being equally refracted and raised, keep the same Distance from one another, and its apparent Magnitude remains the same.

When the Sun is in the Horizon its Rays pass thorough a larger Space of Air than when he is in the Zenith.

Plate XIX.  
Fig. 7.

THE Rays of the Sun, when he is in or near the Horizon, pass thorough a larger Body of Air, than when he is near the Vertex. For let ABD be the Earth, ECF the Orb of Air which surrounds it, whose Altitude is commonly reckon'd to be 50 Miles. Let CA be an horizontal Ray, EA a vertical Ray: It is manifest that CA is longer than EA; and the Proportion of these Lines may be thus found out. Suppose the Semidiameter of the Earth in round Numbers to be 4000 Miles, and EA 50; then is  $TE = CT = 4050$ , whose Square is equal to the Squares of CA and AT: And therefore, if from the Square of CT we take away the Square of TA, there will remain the Square CA; that is, if from 16402500 we subtract 16000000, there will remain 402500, which is the Square of CA, whose Root is 634: And therefore CA: AE :: 634: 50, which is greater than the Proportion of 12 to 1. Hence we see the Reason why without hurting our Eyes, we







CAL

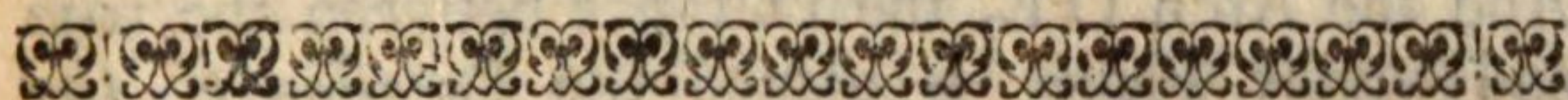
It may be said  
that the  
circle, in  
a plane, is  
the most perfect  
figure, and  
is the basis  
of all geometry.  
It is the only  
figure which  
is perfectly  
symmetrical  
in every direction.

It is the only  
figure which  
is perfectly  
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in every direction.  
It is the only  
figure which  
is perfectly  
symmetrical  
in every direction.



we can look upon the Sun at rising and setting : Lecture  
 But in the Meridian he is not to be looked upon, XXI.  
 without the Danger of hurting our Sight. For the  
 Rays of the Sun in the Horizon penetrating so large  
 a Body of Air, hit against an infinite Number of  
 Particles swimming in it; and being reflected or  
 absorbed, the Force of the Light is thereby much  
 weakned. Since therefore Light is so much weakned  
 in passing through so small a Space as our *Atmo-*  
*sphere*; if this *Atmosphere* were so large as to reach  
 the Moon, and were of the same Density, neither  
 Sun, Moon, nor Stars could then be seen.



## LECTURE XXI.

*Of the Parallaxes of the STARS.*

SINCE all the apparent diurnal Motions  
 are performed uniformly round the  
 Axis of the Earth, and not round the  
 Place of the Spectator, who lives  
 upon the Earth's Surface; he who  
 observes the Motion of the *Stars*  
 from this Surface, must find, that they appear to move  
 with a Motion that is not equal. For, if a Body by  
 its Motion describes equally the Periphery of a Cir-  
 cle, the Equality of Motion can be seen from no  
 other Points than those in the Axis of this Circle.  
 And therefore any *Star* or *Phænomenon*, seen from  
 the Center of the Earth, will appear in a different  
 Place from what it does when observed from the  
 Surface; and this Difference of Place of the same  
*Star*, seen from the Earth's Center and viewed from  
 its Surface, is called the Parallax of that Star.



Lecture  
XXI.

Plate XX.  
Fig. 1.

LET AB be a Quadrant of a great Circle on the Earth's Surface, where A is the Place of the Spectator, and the Point V in the Heavens his Vertex or Zenith. Let VNH represent the Starry Firmament, the Line AD the sensible Horizon, in which suppose the *Star* C to be seen, whose Distance from the Center of the Earth is TC. If this *Star* were observed from the Center T, it would appear in the Firmament in E, and elevated above the Horizon by the Arch DE. This Point E is called the true Place of the *Phænomenon* or *Star*: But an Observer, viewing it from the Surface of the Earth at A, will observe its Place in the Horizon at D, which is called the visible or apparent Place of the *Star*: And the Arch DE, the Distance between the true and visible Place, is named the *Parallax* of the *Star*.

IF the *Star* rise higher above the Horizon to M, its true Place visible from the Center is P; but its visible Place from the Surface is N; and its Parallax is the Arch PN, which is less than the Arch DE. And therefore, the horizontal Parallax is greatest of all Parallaxes; and the higher the *Star* rises, the less is its Parallax: And if it should come to the Vertex, it would have no Parallax at all. For when it is in Q, it is seen both from T and A in the same Line TAV; and there is no Difference between its true and visible Place. The further a *Star* is distant from the Earth, so much the less is its Parallax: So the Parallax of the *Star* F is GD, which is less than the Parallax of the nearer *Star* C. Hence it is plain, that the Parallax is the Difference of the Distances of a *Star* from the Vertex, when seen from the Center, and from the Surface of the Earth. For the true Distance of the *Star* M from the Vertex is the Arch VP; but when observed from A, its visible Distance is VN.

THESE Distances are measured by the Angles VTM and VAM, contained between the Line VT drawn to the Vertex, and the Right Lines TM and AM, drawn from the Center and the Surface



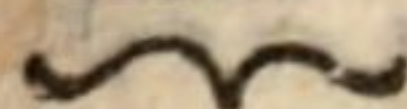
Surface of the Earth to the *Star* M: But the difference of these two Angles is T M A. For the external Angle V A M is equal to the two inward and opposite Angles A T M and A M T: And therefore, A T M is the Difference of the two Angles V A M and A T M or V T M. This Angle A M T does therefore measure the Parallax; and, upon that Account, itself is frequently called the Parallax: And this is always the Angle under which the Semidiameter of the Earth A T appears to an Eye placed in the *Star*: And therefore, where this Semidiameter is seen directly, there the Parallax is greatest, that is, in the Horizon. When the *Star* rises higher, the Parallax is diminished in the Proportion we shall shew in the following *Theorem*.

THE *Sine of the Parallax is to the Sine of the Star's Distance from the Vertex, in a constant and given Proportion; which is, as the Semidiameter of the Earth to the Distance of the Star from the Earth's Center.*

FOR, by a well known Theorem in *Trigonometry*, in the Triangle A T M, the Sine of the Angle A M T is to the Sine of the Angle T A M or V A M, as A T is to T M; that is, in the constant Proportion of the Semidiameter of the Earth to the *Star's* Distance. And therefore, the Sine of the Parallax in C is to the Sine of the Parallax in M, as the Sine of the Angle V A C is to the Sine of the Angle V A M: And therefore, if the Parallax of a *Star* be known when it is at any one Distance from the Vertex, we can find its Parallax at any other Distance from the Vertex. If any *Star* or *Phænomenon* be further distant from the Earth than 15000 Semidiameters of the Earth, its Parallax will be so small, that it will be insensible, and cannot be observed: For, since T F is to T A as 15000 to 1; and, as T F is to T A, so is the Radius to the Sine of the Angle T F A. Hence we shall find the Angle T F A less than 14 Seconds; which Angle is so small, that it cannot be observed by any Instrument.



Lecture  
XXI.



IF we have the Distance of a *Star* from the Earth, we can easily find its Parallax; for, in the Triangle  $TAC$  rectangular at  $A$ , having  $TA$ , the Semidiameter of the Earth, and  $TC$ , the Distance of the *Star*, the Angle  $ACT$ , which is the horizontal Parallax, is found by *Trigonometry*: And again, if we have this Parallax, we can find the Distance of the *Star*; for, in the same Triangle, having  $AT$  and the Angle  $ACT$ , we may find out the Distance  $TC$ .

IF a *Star* has no proper Motion of its own, its true Distance from any fixed *Star*, measured by an Arch of a Circle, always remains unchangeably the same: But, if it have a sensible Parallax, its apparent Distance will be thereby changed; and, if the fixed *Star* be in the same Vertical with the *Phænomenon*, but higher than it, the Distance will appear to grow less as it rises higher. If the *Star* be lower, as they ascend, the Distance will increase; yet seen from the Center, they will appear constantly to keep the same Distance from each other: And therefore, the visible Distances of a *Phænomenon* from a fixed *Star* which is near it, are not the real, but apparent ones.

By the Par-  
rallaxes; the  
Distance of a  
Phænome-  
non from the  
next fixed  
Star is con-  
stantly va-  
riable.

LET there be a *Phænomenon* or *Star* appearing in the Horizon in  $C$ : If it were observed from the Center, it would be seen in Conjunction with the fixed *Star*  $E$ . But the Spectator in  $A$  will see it in the same Line with the *Star*  $D$ , and will be distant from the *Star*  $E$  by the Arch  $DE$ . But as it rises higher into  $M$ , it will still appear, from the Center of the Earth, in Conjunction with the same *Star*  $E$ , which then will appear in  $P$ . But from the Surface of the Earth in  $A$ , it will appear in  $N$ , nearer to the *Star*  $E$  than it was when in the Horizon; and therefore, will not appear in Conjunction with the same *Star*  $D$ , as it did before; but will be distant from it by the Arch  $Nd$ , making the Arch  $Pd$  equal to  $ED$ . Hence it follows, that if any *Phænomenon* always keeps the same Position in respect of the fixed *Stars*, and changes not its arcual Distances from them, it has

no



no sensible Parallax. But even likewise, if its Distance from the *Stars* be changed, yet if that Change be only so much as arises from its proper Motion, in that Case likewise, it will have no sensible Parallax. But if any *Phænomenon* departs further from a fixed *Star*, or comes nearer to it, than what it would do by its proper Motion, this Difference of Access or Recess is the Effect of a Parallax.

THE Parallax of a *Star* in a vertical Circle changes its Place, in regard to the other Circles of the Sphere; and makes its visible Longitude, Latitude and Right-Ascension, to be different from the true ones, which are seen from the Center: And from hence arise four other Kinds of Parallaxes.

LET  $HO$  be the Horizon, whose Pole is  $V$ , Plate XX.  
 $EQ$  the Ecliptick, and its Pole  $P$ ,  $VA$  a vertical Fig. 2.  
 Circle passing thro' the *Star*, whose true Place is  $C$ , but apparent Place  $D$ , in the same Vertical but nearer to the Horizon; so that the Parallax of Altitude is  $DC$ . Thro' the Pole of the Ecliptick and the *Star*, draw the Circle of Latitude  $PCG$ , and  $G$  will be the true Place of the *Star* reduced to the Ecliptick. But a Circle of Latitude, thro' the apparent Place  $D$ , will meet with the Ecliptick in  $H$ , which will be the visible or apparent Place of the *Star* in the Ecliptick: The Arch of the Ecliptick  $GH$ , intercepted between the two Circles of Latitude passing thro' the true and apparent Place, is called the Parallax of Longitude, and  $CN$  the Parallax of Latitude. The Parallax of Longitude.

IF the *Star* be in the vertical Circle, which cuts the Ecliptick in the 90th Degree from the Horizon; *i. e.* in that Vertical which cuts the Ecliptick at Right-Angles; as for Example; in the Point  $c$  of the Circle  $VE$ , the Parallax of Longitude will be nothing. For, because the vertical Circle  $VE$ , is in this Case, perpendicular to the Ecliptick, it will pass thro' its Poles, and will be the same Circle of Latitude in which is the true and apparent Place of the *Star*; and both these  
Places



Lecture XXI. Places reduced to the Ecliptick will coincide in the same Point: And here the Parallax of Latitude will be the same with the Parallax of Altitude.

*The Parallax of Latitude.*

THE Eastern Quadrant of the Ecliptick is that, which lies between the 90th Degree, and the Point of it that rises: The Western Quadrant lies between the 90th Degree, and the setting Point thereof. A *Star*, that is in the Eastern Quadrant, has its apparent Longitude greater than its true Longitude; for, while the *Star* rises, the Parallax depresses it towards the *East*. So in the *Fig.* the visible Place of the *Star* in the Ecliptick is the Point H, which is more Easterly than the true Place G: But if the *Star* be in the Western Quadrant, its visible Longitude is less than the true, because the Parallax thrusts it Westward.

LET the Circle EQ, which before represented the Ecliptick, be now in the Place of the *Æquator*, and P its Pole, PVH the Meridian, VCA a vertical Circle passing through the *Star*; in which let C be its true Place, and D its apparent. PCG, PDH Secondaries of the *Æquator* or Circles of Declination passing through the true and apparent Places of the *Star*, meeting with the *Æquator* in G and H. The Point G shews the true right Ascension of the *Star*, H its apparent, and the Distance GH is called the Parallax of Right-Ascension. The true Declination of the *Star* is GC, and its visible is HD, and their Difference NC is the Parallax of Declination. If a *Star* be to the *East* of the Meridian, the visible Right-Ascension is greater than the true; if to the *West* of it, it is less: And when the *Star* culminates, the Parallax of Right-Ascension is nothing; because the same Circle of Declination does there pass through both the apparent and true Place.

THE *Astronomers* have invented several Methods for finding the Parallaxes of *Stars*, that from thence their Distances from the Earth may be known; for if we knew this, we could make some Estimate of the Largeness and Amplitude of the



the Universe. Let us now give some of the Methods which the *Astronomers* have contrived for searching out the Parallaxes. Lecture XXI.

FIRST, observe the *Star*, when it is in the same vertical Circle with two other fixed *Stars*. *The first way of finding the Parallax.*  
 Let  $VB$  be the vertical Circle, in which are seen the fixed *Stars*  $C$  and  $D$ , and the *Phænomenon* or *Star*  $S$ , whose apparent Place will be likewise in the same Vertical, which suppose to be  $E$ ; and if the *Star* have no proper Motion of its own, it will constantly be in the same Line with the two *Stars*. After some Time, again observe the Position of the *Phænomenon* with the same *Stars*, when it is not in a vertical Circle with them, but rather in a Circle parallel to the Horizon; *i. e.* Suppose the fixed *Stars* in  $c$  and  $d$ , and let the visible Place of the *Star* be  $e$ ; but its true Place is in the Line  $cd$ , which joins the two Fixed. It is also in the Vertical  $Ve$ ; and therefore, it must be in the Point where these Lines cut one another; that is, in  $S$ . Observe the Distances of the fixed *Stars*  $d$  and  $c$ , and of the *Star*  $e$  from the Vertex  $V$ : Measure likewise with an Instrument the Arches  $de$ ,  $ce$  and  $dc$ : And, because  $e$  is the apparent Place of the *Star*, and  $S$  its true Place, the Arch  $eS$  is its Parallax. In the Triangle  $dVc$  we have all the Sides; wherefore, we can find the Angle  $Vdc$ . Again, in the Triangle  $Vde$ , we have all the Sides; therefore, we can find the Angle  $dVe$ . Lastly, In the Triangle  $dVS$  we have the Sides  $dV$ , and the Angles  $dVS$  and  $VdS$ , which we found before; therefore, we can find the Side  $VS$ ; which being subtracted from  $Ve$ , known by Observation, leaves  $Se$  for the Parallax, which was to be found out. Plate XX. Fig. 3.

THE Parallax of a *Star* may be likewise easily found this Way. Observe when the *Phænomenon* is in any Vertical with a fixed *Star* which is near it, and then measure its apparent Distance from this *Star*: Then observe again, when the *Phænomenon* and fixed *Star* are in equal Altitudes from the Horizon; and then again, measure their Distance. *A Second Method.*  
Plate XX.  
Fig. 4.



Lecture XXI.  stance. The Difference of these Distances will be very near the Parallax of the *Star*. For let  $HO$  be the Horizon,  $V$  the Vertex,  $VE$  a vertical Circle passing through the *Star* in  $E$ , and the fixed *Star* in  $D$ . Let the true Place of the *Phænomenon* be  $S$ , so that  $SE$  is the Parallax of Altitude, and the Difference of the *Star's* and the *Phænomenon's* Height is, in this Case, their visible Distance. Afterwards, observe when the *Star* and the *Phænomenon* come to be equally distant from the Horizon, and then measure their Distance by an Instrument: This visible Distance is nearly equal to their true Distance. For let the true Place of the *Phænomenon* be  $s$ ; the Parallax  $se$  is very small in comparison of the Arch  $Ve$ : And therefore  $ds$  and  $de$  will be very near equal; for if the Parallax  $se$  were a whole Degree, yet even then  $ds$  and  $de$  would not differ above one Minute: Therefore the Distance  $de$  being measured, we shall have their true Distance  $ds$  or  $DS$ , which is greater than  $DE$ . And if from  $DS$  we subtract  $DE$ , known by the first Observation, there will remain  $SE$ , the Parallax, which was to be found.

The Third Method.

Plate XX.  
Fig. 5.

THE Parallax of a *Phænomenon* may likewise be obtained by an Observation of its Azimuth and Altitude, and by marking the Time between the Observation and its Arrival at the Meridian. Let  $HVP O$  be the Meridian,  $V$  the Vertex,  $P$  the Pole,  $HO$  the Horizon, and  $VB$  a vertical Circle passing thro' the true and apparent Place; thro' which draw also Circles of Declination  $PS C$ ,  $PE$ . The Arch of the Horizon  $BO$  is the Azimuth of the *Star*; which must be observed, in the Manner we shewed in our last *Lecture*. Observe likewise the Arch  $VE$ , the Distance of the *Phænomenon* from the Vertex, and mark the Moment of Time when these Observations are made. Then stay till the *Phænomenon* or *Star* comes to the Meridian, and note the Moment of its Arrival there; which may be either done by a Pendulum Clock, or by an Observation of a *Star*. Let the



the Distance of the Time between the first Observation and the second of the *Star's* being in the Meridian, be converted into Degrees and Minutes of the *Æquator*, and we shall have the Arch  $\text{ÆC}$ , which measures the Angle  $\text{VPS}$ . Therefore, in the Triangle  $\text{VPS}$ , we have the Side  $\text{VP}$ , the Distance of the Vertex from the Pole, and the Angles  $\text{PVS}$  and  $\text{VPS}$ ; whereby we can find the Arch  $\text{VS}$ , the true Distance of the *Phænomenon* from the Vertex: This being subtracted from the observed Distance  $\text{VE}$ , there will remain the Parallax  $\text{SE}$ , which was to be found.

It is here to be noted, that to reduce the Time into Degrees and Minutes of the *Æquator*, the Time must be first reduced into Hours and Minutes of the *Primum Mobile*, or to the Time of the Revolution of the Heavens, which Hours are somewhat shorter than the Solar Hours: Or if you keep the Solar Hours, you must reckon for each of them 15 Degrees, 2 Minutes, 27 Seconds, and 51 Thirds: And so proportionably for the rest of the Particles of Time.

SUPPOSE  $\text{HO}$  an Arch of the Horizon,  $\text{AM}$  the Meridian, in which  $\text{P}$  is the Pole, and  $\text{V}$  the Vertex of the Place. Suppose  $\text{E}$  the apparent Place of the *Star*; before the *Star* comes to the Meridian, observe the Arch  $\text{VE}$ , its Distance from the Vertex, and its Azimuth  $\text{EVM}$ : Let the true Place of the *Star* be  $\text{S}$ , its Parallax is  $\text{SE}$ : Mark the Time of the Observation. Again, after the *Star* has passed the Meridian, observe when it is exactly at the same Distances from the Vertex, so that  $\text{Ve}$  may be equal to  $\text{VE}$ : And here, since the visible Distances of the *Star* from the Vertex are equal, the real Distances will be likewise equal, *i. e.*  $\text{VS} = \text{Vs}$ . Take the Time between the first and second Observation, and turn it into Degrees and Minutes of the *Æquator*, and we shall have the Angle  $\text{SPs}$ , the Half of which is the Angle  $\text{SPV}$ . Therefore, in the Triangle  $\text{SVP}$ , we have the Angle  $\text{SPV}$ , and the Angle  $\text{SVP}$ , which is the Complement of the Azimuth to two Right-

A Fourth  
Method.Plate XX.  
Plate 6.



Lecture XXI. Right-Angles; also the Side  $VP$ , the Distance of the Pole and Vertex; from them we shall know  $VS$ , the true Distance of the *Star* from the Vertex; which being subtracted from  $VE$ , leaves  $SE$  for the Parallax.

*The Fifth Method.*

THESE Practices depend upon Observations of the Azimuths; but without observing them the Parallax may be known, by finding out the apparent and true Right-Ascensions; and from them, by Calculation, finding the Azimuth: For by observing the Distance of a *Phænomenon* from two known fixed *Stars*, we can compute its apparent Right-Ascension, according to the Method explained in *Lecture XIX*: Then again, when the *Star* comes to the Meridian, by the same Method find its Right-Ascension; which is the true Right-Ascension, or the Point where the Circle of Declination, passing through the true Place of the *Star*, cuts the *Æquator*. Knowing then the apparent Right-Ascension of the *Star* in the Vertical  $VB$ , and the Point of the *Æquator* which at the same Time culminates, we shall likewise know the Angle  $VPE$ : Therefore, in the Triangle  $VPE$ , having the Sides  $VP$ ,  $VE$ , and the Angle  $VPE$ , we can find the Angle  $PVE$ , which determines the Azimuth. But having the true Right-Ascension of the *Star* as was observed in the Meridian, and the Point of the *Æquator* culminating at the first Observation, the Distance between them will give us the Angle  $VPS$ . Therefore, in the Triangle  $VPS$ , having the two Angles  $VPS$  and  $SV P$ , as also the Side  $VP$ , we can find the Side  $VS$ , the real Distance of the *Star* from the Vertex; which subtracted from  $VE$ , leaves  $SE$ , the Parallax, which was to be found.

Plate XXI.  
Fig. 1.

IN determining the Right-Ascensions of the *Stars*, we are not to rely too much, in so nice an Affair as the Parallax is, on a Pendulum Clock for determining the Time; for there the Error of one Second in numbering being made, will produce an Error of Right-Ascension of 15 Seconds.

FOR,



FOR, to observe the Right-Ascension of a *Star*, Lecture  
 there is no need of staying till it come to a Me- XXI.  
 ridian; but it is more easily and certainly had by  
 two Observations, one made in the Eastern Qua-  
 drant, and the other in the Western Side of the  
 Heavens; but both must be made when the *Star* is  
 at the same Height above the Horizon: For if we  
 take the Distance of the *Phænomenon* from two  
 known fixed *Stars*, when it is in the Eastern Re-  
 gion, we shall by that Means find its apparent Right-  
 Ascension, which is greater than the true, because  
 the Parallax depresses a *Star* more Eastern. Again,  
 when the *Star* descends on the Western Side, and  
 comes to the same Height, let its Distance be like-  
 wise observed from two fixed *Stars*, and get from  
 them its apparent Right-Ascension, which is just  
 as much less than the true, as the former exceeded  
 it. And therefore, if the Differences between the  
 two apparent Right-Ascensions be halved, and this  
 Half be added to the least or subtracted from the  
 greatest, we shall have the true Right Ascension,  
 or the Point in the *Æquator* where it meets  
 with the Circle of Declination passing through the  
*Star*, that is, the Point C. But from the Time of Table XX-  
 the Observation, we have the Point of the *Æqua*- Fig. 5.  
*tor* which culminated at that Moment; and con-  
 sequently, we have the Arch  $\text{Æ C}$ , and the Angle  
 $\text{Æ P C}$  measured by it: Therefore, in the Triangle  
 $\text{V P S}$ , having the Side  $\text{V P}$ , and the Angles  $\text{V P S}$   
 and  $\text{P V S}$ , we can find the Side  $\text{V S}$ , the true Di-  
 stance of the *Phænomenon* from the Vertex; which  
 subducted from the apparent Distance, there will  
 remain  $\text{S E}$ , the Parallax required.

THE easiest and best Way of finding the Par- The Sixth  
 allax of Right Ascension is by a Telescope, in Method.  
 whose *Focus* are four Threads, crossing one another  
 at half Right-Angles, as we shewed in our XIXth  
*Lecture*. Directing this Telescope to the *Star*, Table XXI.  
 turn it constantly round, till its apparent diurnal Fig. 2.  
 Motion appear to be along the Thread  $\text{A B}$ ; in  
 which Position, the Thread will represent a Por-  
 tion of the Parallel which the *Phænomenon* de-  
 scribes;

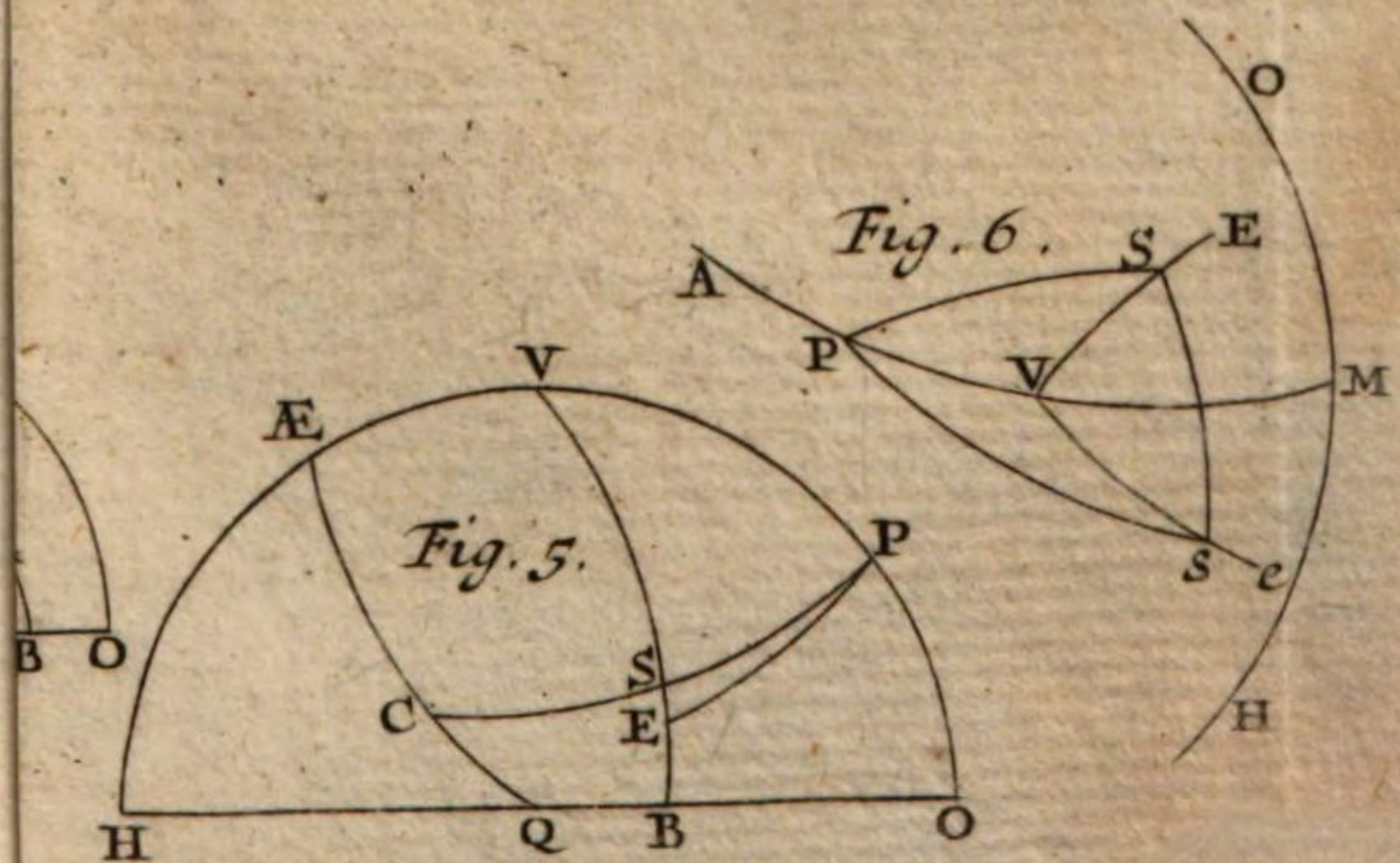
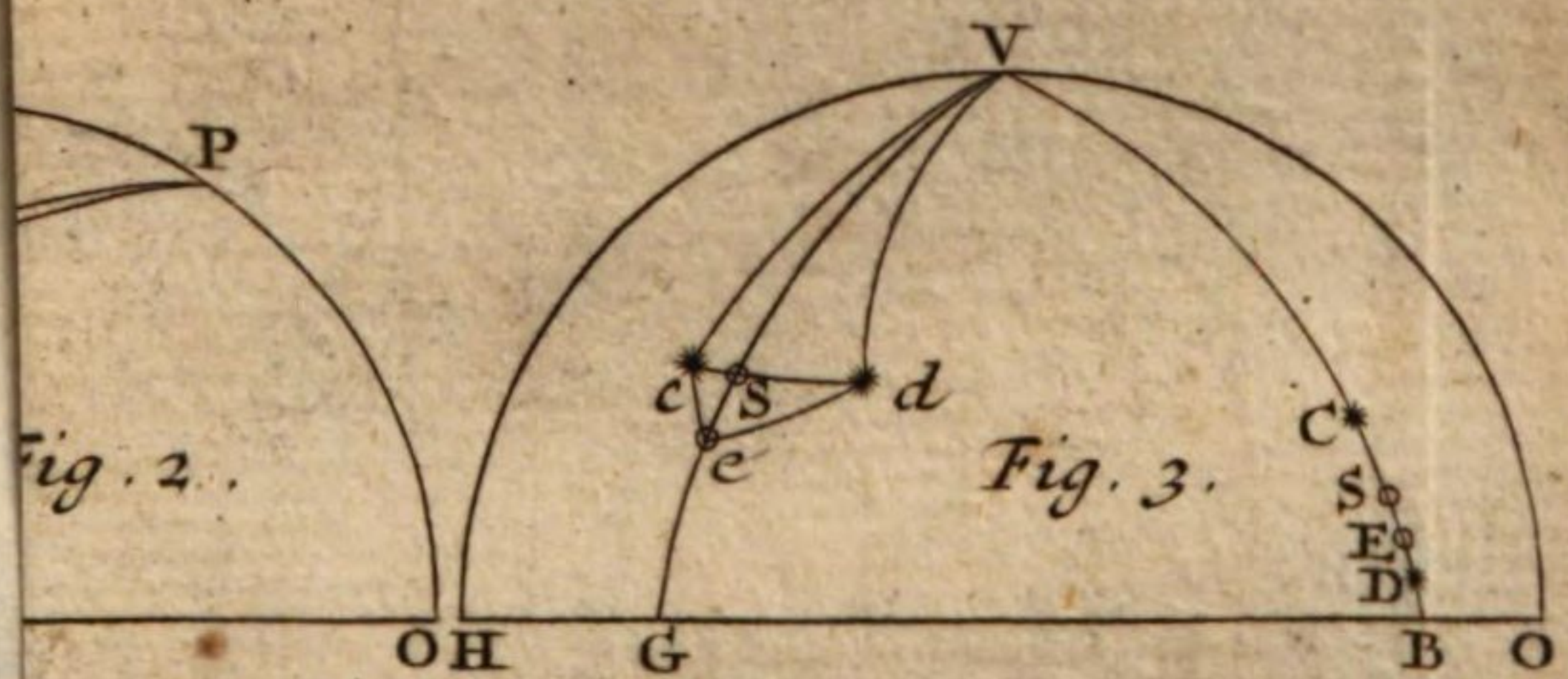
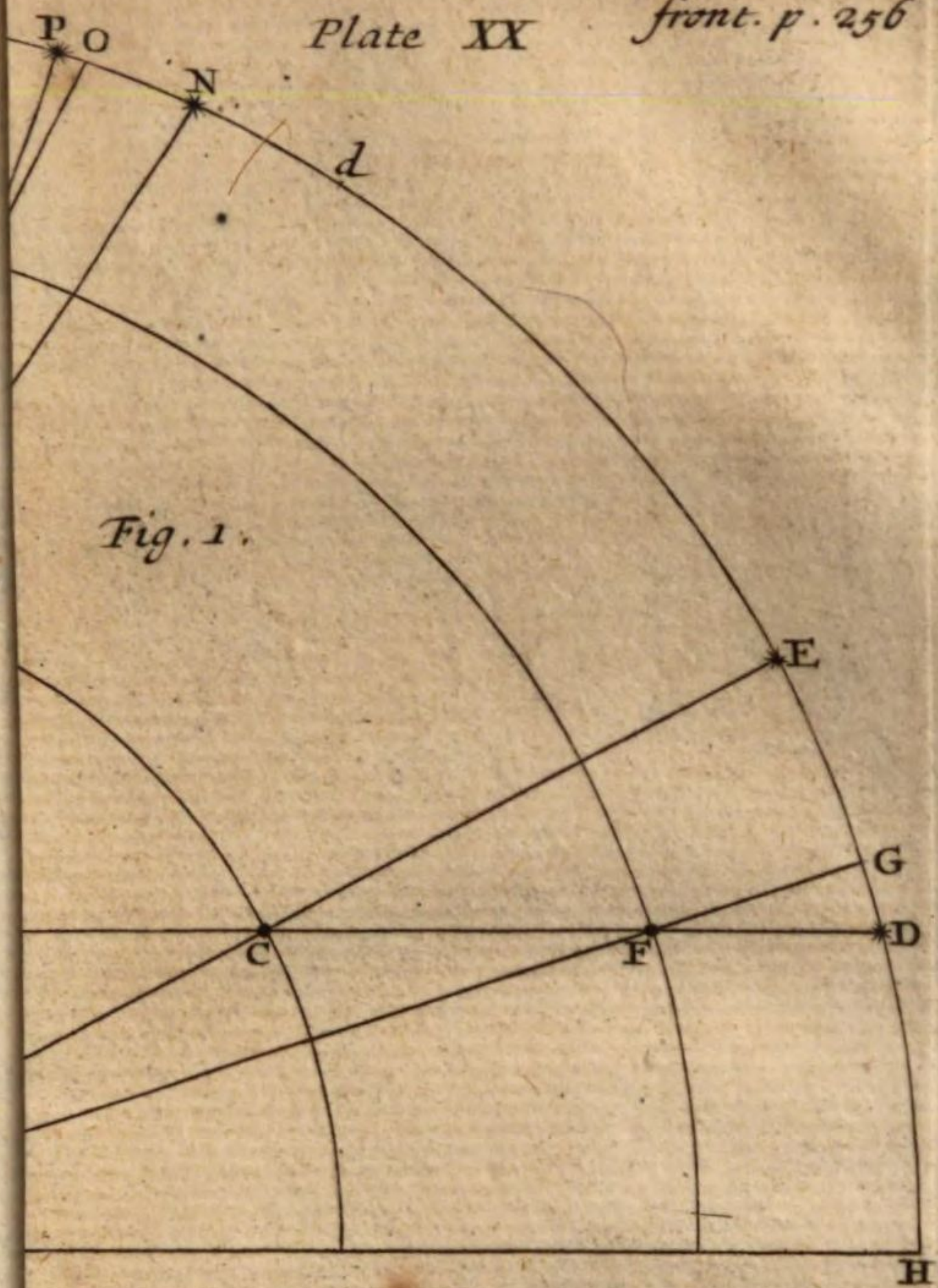


Lecture XXI. scribes; and the Thread CD, cutting it at Right-Angles, will represent a Horary Circle. Observe

therefore the Time when the *Phænomenon* is seen in the Horary Circle. The Telescope remaining thus fixed and unmoved, observe the Time when any other *Star*, whose Right-Ascension is known, comes to the same Horary Circle: The Distance of Time between the Appulse of the *Phænomenon* to the Horary Circle, and of the fixed *Star* to the same Circle, being turned into Degrees and Minutes of the *Æquator*, will shew the Difference of Right-Ascensions of the *Star* and the *Phænomenon*. Again, when the *Star* comes to the Meridian observe it with the Telescope, and by the same Method find out its Right-Ascension, which will be the true one; and by it we shall have the Point of the *Æquator*, where the Circle of Declination, passing thro' the true Place of the *Star*, does cut the *Æquator*. Having therefore the true Right-Ascension and the apparent, we have their Difference, or the Parallax of Right-Ascension. And because we have the apparent Right-Ascension and the Point of the *Æquator* then culminating, we have the Arch of the *Æquator*, intercepted between them, which is the Measure of the Angle V P E. Therefore, in the Triangle V P E, we have the Sides VP, P E, and the Angle V P E, whence we find the Angle P V E. From the Angle V P E take the Angle S P E, the Parallax of Right-Ascension, and we shall have the Angle V P S. Lastly, In the Triangle V P S, having the Angles V P S and P V S, together with the Side V P, we can from them find the Side V S, the true Distance of the *Star* from the Vertex; which being subtracted from the apparent Distance, leaves the Parallax that was to be found.

*The Method of finding the Parallax when the Star has a proper Motion of its own.* IF the *Phænomenon* have a proper Motion of its own, its Right-Ascension will constantly be changed by this Motion, unless it should happen to move in some Circle of Declination: And therefore, Care must be taken to determine the Change of Right-Ascension, that arises by the Motion of the *Star*; which is done, by observing the











the right Ascension of the *Star*, when it is in the Meridian; and the next Day, let its right Ascension be in the same Manner observed. The Difference of these right Ascensions will shew the Change that the right Ascension has, for the Time between the two Observations: And from them we can find the Change of right Ascension, or the Motion of the *Phænomenon* along the *Æquator* in a Day: From this diurnal Motion we can find by proportioning the Motion for any given Time. For Example, If the diurnal Motion according to the *Æquator* be 30 Min. that is, suppose the *Phænomenon* advanced according to the *Æquator* every Day 30 Minutes; and suppose the Time between the Observation on the Eastern Side of the Heaven, and that in the Meridian be six Hours, the Motion according to the *Æquator* in that Time is  $7\frac{1}{2}$  Minutes; let the Difference of right Ascension, observed in the Vertical and in the Meridian, be 20 Minutes, seven and a half of those Minutes are owing to the proper Motion of the Body; wherefore, the Parallax of right Ascension is  $12\frac{1}{2}$  Minutes.

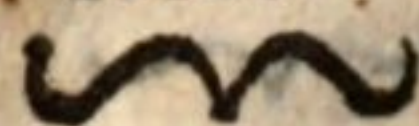
AFTER the same Manner by the apparent and real Longitude of a *Phænomenon*, the Parallaxes may be investigated. The apparent Longitude is found, by observing the Distance of a *Phænomenon* from two fixed *Stars*, whose Longitudes and Latitudes are known. And the true Longitude is had, by making the same Observations, when the *Star* is in the 90th Degree of the *Ecliptick*, where the apparent and true Longitudes coincide.

By these, and the like Methods, if any *Phænomenon* has a Parallax not less than one Minute, it may be found out. In the Moon we find the Parallax very considerable, which in the Horizon amounts to about a Degree or more. But there are some particular Methods, only applicable to the Moon, by which its Parallax is known.

IN an Eclipse of the Moon, observe when both its Horns are in the same vertical Circle, and then in that Moment take the Altitudes of both Horns: *A Method for observing the Parallax of the Moon.*



Lecture  
XXI.



Horns: The Difference of these two Altitudes being halved and added to the least, or subtracted from the greatest, does give nearly the visible Altitude of the Moon's Center: But the true Altitude is nearly equal to the Altitude of the Center of the Shadow at that Time. Now we know the Altitude of the Center of the Shadow, because we know the Place of the Sun in the Ecliptick, and its Depression under the Horizon, which is equal to the Altitude of the opposite Point of the Ecliptick, in which is the Center of the Shadow. And therefore we have the true Altitude of the Moon, and the apparent Altitude, whose Difference is the Parallax, which will therefore be known.

Tables of  
the Moon's  
Parallaxes.

As the Distance of the Moon grows less, according as it recedes from its *Apogæum*, her Parallax must in the same Proportion be encreased constantly, the nearer she comes to us. Therefore the Artists make Tables, which shew the horizontal Parallax for every Degree of its Anomaly.

THE Methods we have given for finding the Parallaxes, shew, that the Moon has a great Parallax, and is very near us; but none of them is sufficient for finding out the Parallax of the Sun: For that is so small, that the Observations requisite cannot be made accurately enough for to determine it; for an Error in observing can scarcely be avoided, which is not equal or greater than the Sun's Parallax. This defect of Observations put the antient *Astronomers* on the Search of other Methods peculiar to the Sun, for finding out its Parallax: But even those Methods, though they make manifest the Acuteness and Sagacity of the Antients, yet are not sufficient in so nice and subtle a Disquisition. However, they are useful to shew, that the Distance of the Sun from the Earth is very great in Comparison of the Moon's Distance from the same: And therefore it will not be unfitting to explain them in this Place.

Hippar-  
chus's Me-  
thod for the  
Parallax of  
the Sun.

THE first Method was invented by *Hipparchus*, and has been made use of by *Ptolemy* and his Followers, and many other *Astronomers*. It depends on



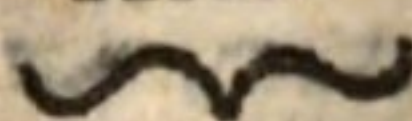
on an Observation of an Eclipse of the Moon: And Lecture the Principles on which it is founded are, *First*, In XXI. a Lunar Eclipse the horizontal Parallax of the Sun is equal to the Difference between the apparent Semidiameter of the Sun, and half the Angle of the Conical Shadow; which is easily made out in this Manner. Let the Circle AFG represent the Sun, Plate XXI. and DHE the *Earth*; let DHM be the Shadow, Fig. 3. and DMC the half Angle of the Cone. Draw from the Center of the Sun the right Line SD touching the Earth, and the Angle DSC is the apparent Semidiameter of the Earth, seen from the Sun, which is equal to the horizontal Parallax of the Sun; the Angle ADS is the apparent Semidiameter of the Sun, seen from the Earth: The external Angle ADS is equal to the two Internals DMS and DSM, by the 32d *Prop. Elem. I.* And therefore the Angle DSM, or DSC is equal to the Difference of the Angles ADS and DMS. *2dly*, Half the Angle of the Cone is equal to the Difference of the horizontal Parallax of the Moon, and the apparent Semidiameter of the Shadow, seen from the Earth at the Distance of the Moon. For let CDE be Plate XXI. the Earth, CME the Shadow, which at the Di- Fig. 4. stance of the Moon being cut by a Plane, the Section will be the Circle FLH, whose Semidiameter is FG, and is seen from the Center of the Earth under the Angle FTG. But by the 32d *Prop. Elem. I.* the Angle CFT is equal to the two Internals FMT and FTM. Wherefore the Angle FMT is the Difference of the two Angles CFT and GTF: But the Angle CFT is the Angle under which the Semidiameter of the Earth is seen from the Moon, and this is equal to the horizontal Parallax of the Moon; and the Angle GTF is the apparent Semidiameter of the Shadow seen from the Earth's Center. It is therefore evident that the half Angle of the Cone is equal to the Difference of the horizontal Parallax of the Moon, and the apparent Semidiameter of the Shadow seen from the Earth. Wherefore, if to the apparent Semidiameter of the

S 2

Sun



Lecture  
XXI.



Hippar-  
chus's Me-  
thod insuffi-  
cient.

Sun there be added the apparent Semidiameter of the Shadow, and from the Sum you take away the horizontal Parallax of the Moon, there will remain the horizontal Parallax of the Sun; which therefore, if these were accurately known, would be likewise known accurately: But none of them can be so exactly and nicely obtained, as to be sufficient for determining the Parallax of the Sun; for very small Errors, which cannot be easily avoided in measuring these Angles, will produce very great Errors in the Parallax; and there will be a prodigious Difference in the Distances of the Sun, when drawn from these Parallaxes. For Example: Suppose the horizontal Parallax of the Moon to be  $60' 15''$ , the Semidiameter of the Sun  $16$ , and the Semidiameter of the Shadow  $44' 30''$ ; we should conclude from thence, that the Parallax of the Sun was  $15''$ , and his Distance from the Earth about  $13700$  Semidiameters of the Earth. But if there be an Error committed, in determining the Semidiameter of the Shadow, of  $12''$  in Defect, (and certainly the Semidiameter of the Shadow cannot be had so precisely, as not to be liable to such an Error) that is, if instead of  $44' 30''$  we put  $44' 18''$  for the apparent Diameter of the Shadow, all the others remaining as before, we shall have the Parallax of the Sun  $3''$ , and its Distance from the Earth almost  $70000$  Semidiameters of the Earth, which is five Times more than what it was by the first Position. But if the Fault were in Excess, or the Diameter of the Shadow exceeded the true by  $12''$ ; so that we should put in  $44' 42''$ , the Parallax would arise to  $27''$ , and the Distance of the Sun only  $7700$  of the Earth's Semidiameter; which is nine times less than what it comes to by a like Error in Defect. If an Error in Defect was committed of  $15''$ , which is still but a small Mistake, the Sun's Parallax would be equal to nothing, and his Distance infinite. Wherefore, since from so small Mistakes the Parallax and Distance of the Sun vary so much, it is plain that the Distance of the Sun cannot be obtained by this Method.

SINCE



SINCE therefore the Angle that the Earth's Semidiameter subtends at the Sun is so small, that it cannot be determined by any Observation; *Aristarchus Samius*, an ancient and great *Philosopher* and *Astronomer*, contrived a very ingenious Way for finding the Angle which the Semidiameter of the Moon's Orbit subtends, when seen from the Sun: This Angle is about sixty times bigger than the former, subtended only by the Earth's Semidiameter. To find this Angle, he lays down the following Principles.

*Aristarchus's Method for the Sun's Distance.*

IN that *Lecture* where we explained the *Phases* of the Moon, we shewed, that if a Plane passed thro' the Moon's Center, to which the Line joining the Sun and Moon's Center was perpendicular, this Plane would divide the illuminated Hemisphere of the Moon from the dark one: And therefore, if this Plane should likewise pass thro' the Eye of a Spectator on the Earth, the Moon would appear bisected, or like a half Circle; and a right Line, drawn from the Earth to the Center of the Moon, would be in the Plane of Illumination, and consequently would be perpendicular to the right Line which joins the Centers of the Sun and Moon. Let S be the Sun, and T the Earth, A L  $\frac{1}{4}$  a Quadrant of the Moon's Orbit; and let the Line S L, drawn from the Sun, touch the Orbit of the Moon in L; the Angle T L S will be a right Angle: And therefore, when the Moon is seen in L, it will appear bisected, or just half a Circle. At the same Time take the Angle L T S the Elongation of the Moon from the Sun, and then we shall have the Angle L S T its Complement to a right Angle. But we have the Side T L, by which we can find the Side S T, the Distance of the Sun from the Earth.

Table XXI.  
Fig. 5.

BUT the difficult Point is to determine exactly the Moment of Time when the Moon is bisected, or in its true *Dichotomy*; for there is a considerable Space of Time both before and after the *Dichotomy*, nay, even in the Quadrature, when the Moon will appear bisected, or half a Circle; so

*Aristarchus's Method insufficient.*



Lecture XXI. that the exact Moment of Bisection cannot be known by Observation, as Experience tells us: This can be also made out by the following Reason. *Pag. 95. in the Lecture concerning the Phases of the Moon, it was demonstrated, that the Diameter of the Moon was to the Portion of it illustrated by the Sun, and seen by us, as the Diameter of a Circle is to the Versed Sine of the Elongation of the Moon from the Sun, nearly: But accurately, it is as the Diameter of a Circle to the Versed Sine of the exterior Angle at the Moon, of the Triangle formed by Lines joining the Centers of the Sun, Earth, and Moon, as we shewed in the Lecture, pag. 163. concerning the Phases of Venus.* Let us suppose, in the Time of true *Dichotomy* or Bisection, that the Angle  $LST$  is  $15'$ , and that the Semidiameter of the Lunar Orbit were 60 Semidiameters of the Earth; the Distance of the Sun would in that Case be 13758 of the Earth's Semidiameters. This being supposed, let us imagine the Moon to be in her Quadrature at  $q$ ; that is, let the Angle  $qTS$  be a right Angle, the exterior Angle of the Triangle  $qTS$  at  $q$  would be  $90^\circ. 15'$ , whose *Versed Sine* is equal to the Radius and the right Sine of  $15'$  together: Therefore, as the Diameter of a Circle is to the Radius  $+ \text{Sine } 15'$ ; so is the Diameter of the Moon to that Part of it which is illustrated by the Sun, and seen from the Earth. Wherefore, taking half the Antecedents, and by Division of Ratio, the Radius will be to the right Sine of  $15'$ , as is the Semidiameter of the Moon to that Excess, wherewith the illuminated Part seen from the Earth is greater than half the Moon's Diameter. Now the Sine of  $15'$  is 436, of such Parts as the Radius is 100000, and the apparent Semidiameter of the Moon is about  $15'$ : Say therefore, as 100000 is to 436, so is  $15'$  to a Fourth, which is less than  $4''$ ; but this is so small a Quantity, that it is not in the least to be perceived by our Senses: And therefore the Moon, even in the Quadratures, has its Illumination exceeding the bisected Illumination by such a Quantity as is altogether



gether imperceptible: But if the real *Dichotomy* or Bisection were in the Quadrature, the Distance of the Sun would be in Infinite; for in that Case the Angles  $STq$  and  $SqT$  being right, the Lines  $ST$  and  $Sq$  would be parallel, and would not meet but at an infinite Distance.

2dly, SUPPOSE the Elongation of the Moon from the Sun  $89^{\circ} 30'$ : In that Case the exterior Angle at the Moon is  $89^{\circ} 45'$ , and its *Versed Sine* equal to the Radius bating the right Sine of  $15'$ . And because as the Radius is to the *Versed Sine* of the exterior Angle, that is, to the Radius diminished by the Sine of  $15'$ ; so is the Semidiameter of the Moon to that Part of it which is illustrated and seen by us; then, by Division of *Ratio*, the Radius will be to the Sine of  $15'$ ; as is the Moon's Semidiameter to that Part whereby the Semidiameter of the Moon is greater than the illuminated Part thereof which is seen by us; which therefore (as in the former Case) will be scarce  $4''$ : Now the Moon, wanting but so small a Portion to be intirely bisected, will appear to us as if she were really bisected; so that its *Phasis* can in no wise be distinguished from the true *Phasis* of a *Dichotomy*: And therefore, if this apparent *Phasis* should be taken for the true *Phasis* of the *Dichotomy*, which is half a Degree distant from the Quadrature, we should find the Distance of the Sun from us to be 6876 Semidiameters of the Earth.

OBSERVATIONS inform us, that when the Moon is 30 Min. distant from the Quadratures it appears bisected; and in the Quadrature its *Phasis* cannot be perceived to be different from a bisected *Phasis*: Nay, the Moon, observed with the best Telescopes, after it has past the Quadratures, appears bisected, as *Ricciolus* himself acknowledges in his *Almagest*, p. 734. And therefore the Moon, at least for the Space of one Hour, appears to be bisected, in which Time any Moment may be taken for the true Point of the *Dichotomy*, as well as any other: And for the infinite Number of Moments of Time, we



Lecture shall have an infinite Diversity of Distances of the  
 XXI. Sun from the Earth: And consequently, the true  
 Distance of the Sun from the Earth cannot be obtained by this Method.

SINCE the Moment in which the true *Dichotomy* happens is uncertain, but it is certain that it happens before the Quadrature; *Ricciolus* takes that Point of Time which is in the Middle, between the Time that the *Phasis* begins to be doubtful whether it be bisected or not, and the Time of Quadrature: But he had done righter, if he had taken the middle Point between the Time when it becomes doubtful whether the Moon's Side is concave or streight, and the Time again when it is doubtful whether it is streight or convex; which Point of Time is after the Quadrature: And if he had done this, he would have found the Sun's Distance a great deal bigger than he has made it.

There is no need to confine this Method to the *Phasis* of a *Dichotomy* or Bisection.

THERE is now no need to confine this Method to the *Phasis* of a *Dichotomy* or Bisection, for it can be as well perform'd when the Moon has any other *Phasis* bigger or less than a *Dichotomy*: For observe by a very good Telescope, with a Micrometer, the *Phasis* of the Moon, that is, the Proportion of the illuminated Part of the Diameter to the whole; and at the same Moment of Time take her Elongation from the Sun: The illustrated Part of the Diameter, if it be less than the Semidiameter, is to be subducted from the Semidiameter; but if it be greater, the Semidiameter is to be subducted from it, and mark the Residue: Then say, as the Semidiameter of the Moon is to the Residue, so is the Radius to the Sine of an Angle, which is therefore found: This Angle added to, or subtracted from a right Angle, gives the exterior Angle of the Triangle at the Moon: But we have the Angle at the Earth, which is the Elongation observed; which therefore being subducted from the exterior Angle, leaves the Angle at the Sun. And in the Triangle *SLT*, having all the Angles and one Side *LT*, we can find the other Side *ST*, the Distance of the Sun from



from the Earth. But it is almost impossible to determine accurately the Quantity of the Lunar *Phases*, so that there may not be an Error of a few Seconds committed; and consequently, we cannot by this Method find precisely enough the true Distance of the Sun. However, from such Observations, we are sure, that the Sun is above 7000 Semidiameters of the Earth distant from us. Since therefore the true Distance of the Sun can neither be found by Eclipses, nor by the *Phases* of the Moon, the *Astronomers* are forced to have Recourse to the Parallaxes of the Planets that are next to us, as *Mars* and *Venus*, that are sometimes much nearer to us than the Sun is: Their Parallaxes they endeavour to find by some of the Methods above explained: And if these Parallaxes were known, then the Parallax and Distance of the Sun, which cannot directly by any Observations be attained, would easily be deduced from them. For from the Theory of the Motions of the Earth and Planets, we know at any Time the Proportion of the Distances of the Sun and Planets from us; and the horizontal Parallaxes are in a reciprocal Proportion to these Distances. Wherefore, knowing the Parallax of a Planet, we may from thence find the Parallax of the Sun.

*MARS*, when he is in an Acronychal Position, that is, opposite to the Sun, is twice as near to us as the Sun is; and therefore his Parallax will be twice as great. But *Venus*, when she is in her inferior Conjunction with the Sun, is four-times nearer to us than he is, and her Parallax is greater in the same Proportion: Therefore, tho' the extreme Smallness of the Sun's Parallax renders it unobservable by our Senses, yet the Parallaxes of *Mars* or *Venus*, which are twice or four-times greater, may become sensible. The Astronomers have bestowed much Pains in finding out the Parallax of *Mars*; but of late, *Mars* was in his Opposition to the Sun, and also in his *Perihelion*, and consequently, in his nearest Approach to the Earth: And

*The Sun's Distance and Parallax may be deduced from the Parallax of the Planets.*

*Particularly by Mars in an Acronychal Position.*



Lecture XXI. And then he was most accurately observed by two of the most eminent *Astronomers* of our Age, who have determined his Parallax to have been scarce 30 Seconds; from whence we can easily collect, that the Parallax of the Sun is scarce 11 Seconds, and his Distance about 19000 Semidiameters of the Earth.

The Parallax of the Sun found by observing Venus in the Body of the Sun.

By an Observation of the Body of *Venus*, seen passing over the Body of the Sun, which will happen in *May*, 1761, Dr. *Halley* has shewed a Method of finding the Parallax and Distance of the Sun to a great Nicety, viz. within a five hundredth Part of the whole; and we must wait till then, before it can be determin'd to so great an Exactness.

BECAUSE the Method whereby the *Astronomers* foretel Eclipses of the Sun, requires that the Moon's Parallax both as to Longitude and Latitude should be known by Calculation: And also, as often as the Moon's Place in the Heavens is to be observed, that it may be compared to the Place found by *Astronomical* Tables, in order to establish her Theory; it will be necessary to reduce the true Place found by the Tables to her apparent Place, which cannot be done without the Calculation of the Parallax: It will be convenient to explain the Method by which the Moon's Parallax for any Point of Time is to be calculated.

How the Moon's Parallax is to be found for any Time by Calculation.

Table XXI.  
Fig. 6.

FIRST, by *Astronomical* Tables compute the Place of the Moon in the Ecliptick and her Latitude, for the given Time. In the Figure suppose *HO* the Horizon, *HZO* the Meridian, *Z* the Vertex, *EC* the Ecliptick, in which let *L* be the Place of the Moon, found by the Tables. And first, let us suppose the Moon to be without Latitude. From the Vertex *Z* let fall upon the Ecliptick the Perpendicular *ZnA*, which will be therefore a Circle of Latitude; and the Point *n* will be the 90th Degree of the Ecliptick. From the Time given we have the right-Ascension of the Sun, and his Equatorial Distance from the Meridian: From thence we shall find



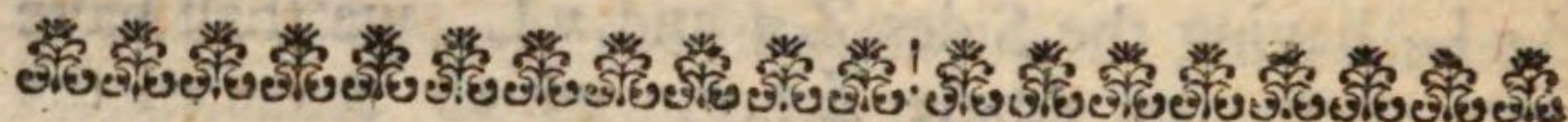
find the Point of the *Æquator* culminating, which is the right Ascension of Mid-Heaven, or of that Point of the *Ecliptick* which culminates: And therefore we know that Point which is then in the Meridian, as also the Angle  $ZE\pi$  of the *Ecliptick* and Meridian. This is either found by the Calculation we explained in the *spherical Doctrine*, or by Tables of *Astronomy*: By this Means we find the Arch  $EL$ ; but we have the Arch  $E\mathcal{A}$  the Declination of the Point  $E$ , and consequently the Arch  $ZE$  will be known. Therefore in the right-angled Triangle  $Z\pi E$ , we have the Side  $ZE$ , and the Angle  $ZE\pi$ . Hence we can find  $E\pi$  and the Point  $\pi$  or the Point of the 90th Degree, and the Arch  $Z\pi$ , its Distance from the Vertex; whose Complement  $\pi A$  is the Measure of the Angle that the Horizon and the *Ecliptick* make: And because we have the Place of the Moon, we must have the Arch  $\pi L$ . Therefore in the right-angled Triangle  $Z\pi L$ , having the Sides  $Z\pi$  and  $\pi L$ , we shall have from them the Angle  $ZL\pi$ , which is called the *Parallactick Angle*, as likewise the Side  $ZL$ , the Distance of the Moon from the Vertex. Let the Radius be to the Sine of the Arch  $ZL$ , as the horizontal Parallax of the Moon taken from the Tables to its Parallax in  $L$ , which therefore is found. Let it be  $oL$ . From  $o$  on the *Ecliptick* let fall the Perpendicular  $om$ . And in the Triangle  $oLm$  (which being very small, may be taken for a rectilinear one) we have besides the right Angle, the Side  $Lo$  and the Angle  $oLM$  equal to  $ZL\pi$ ; wherefore we shall find out the Arch  $Lm$ , the Parallax of Longitude, and  $om$ , the Parallax of Latitude, which were to be found.

The Paral-  
lactick Ang  
gle.

SUPPOSE now the Moon has some Latitude, and its Place in the *Ecliptick* be the Point  $L$ , but let it be placed in the Circle of Latitude  $LP$  at  $P$ . And because the Angle  $\pi LP$  is right, and we have the Angle  $\pi LZ$ , and its Complement  $ZLP$ ; in the Triangle  $ZLP$  we have two Sides,  $ZL$ , which was found before, and  $LP$ , the Moon's Latitude, and the



Lecture XXII. the Angle  $ZLP$ , whereby we can find out the Side  $ZP$ , and the Angle  $ZPL$ . Let the Radius be to the Sine of the Arch  $ZP$ , as the horizontal Parallax of the Moon to a Fourth, which will be  $Pq$ : This will be the Parallax of the Moon in the Circle of Altitude. Let  $qd$  be an Arch parallel to the Ecliptick; and in the small Triangle  $Pdq$ , which may be taken as a right-angled Triangle, we have the Angle  $dPq$ , which is the Complement of the Angle  $ZPL$  to two right Angles, and the Side  $Pq$ : Therefore we shall have  $Pd$  the Parallax of Latitude, and  $qd$  the Parallax of Longitude: For because the Latitude of the Moon is but small, the Arch of the Parallel  $dq$  is nearly equal to the Arch of the Ecliptick which is correspondent to it.



## LECTURE XXII.

### *The Theory of the Annual Motion of the EARTH.*



HERETO we have given an Account of the general Affections of the Planets Motions, and have explained the Appearances which arise from their Motions and the Motions of the *Earth* together. We will now come to their particular Theories, in which the Period of each, its Distance from the Sun, the Form of its Orbit, and its Position are determined; which











which being once known, the Place of any Planet in the *Zodiack* may be computed for any given Time. And because the Theories of the Planets are founded on the Motion of the *Earth*, and are investigated by this Motion, it will be necessary to begin with the Theory of the *Earth*.

In our VIIth *Lecture* we shewed how the Motion of the *Earth* round the Sun was the Cause of the Appearance of the annual Motion of the Sun in the *Ecliptick*; and that the Sun, observed from the *Earth*, seemed to describe the same Circle in the Heavens, that a Spectator in the Sun would see the *Earth* really to move in. But the Place of the *Earth* seen out of the Sun is always diametrically opposite to that Point of the *Ecliptick* in which we on the *Earth* observe the Sun to be placed: And therefore when the Sun appears to us in  $\gamma$ , the *Earth* is really in  $\varpi$ ; when he is in  $\odot$ , the *Earth* has its Mansion in  $\varphi$ . And therefore from the apparent Place of the Sun, which we find out by Observation, we can easily determine the Place of the *Earth* in its proper Orbit.

SINCE the *Ecliptick* cuts the *Æquator* in two opposite Points, the Sun will twice every Year appear in the *Æquator* or *Equinoctial Circle*; which happens when by his apparent Motion he arrives at the Intersections of these two Circles: All the rest of the Year he will seem to decline either to the North or South from the *Æquator*; and he is at his farthest Distance from the *Æquator*, when he is just in the Middle between the two Sections, that is, 90 Degrees removed from either, and there the Sun does not seem to alter his Declination for some Time; and then the Days keep the same Length: And therefore these Points which are the first of  $\odot$  and  $\varphi$  are called the *Solstitial Points*, as the Intersection of the *Æquator* and *Ecliptick*, are called the *Equinoctial Points*, because, when the Sun is seen in them, the Days and Nights are equal.

SINCE



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SINCE the Sun is seen continually moving in the Ecliptick, and every Day seems to advance a Degree Eastward, he makes no Stay in the Equinoctial Points ; but in passing on, in the same Moment he arrives there, he leaves them : And therefore, though the Day the Sun enters the Equinoctial Point is called the *Equinox*, because it is reputed equal to the Night ; yet it is not precisely so, unless the Sun enters the *Æquator* at Mid-day. For if the rising Sun should enter the Vernal Equinox, at Setting he will have departed from it, and decline Northwards about the Space of  $12'$  ; and therefore, that Day will be somewhat longer than 12 Hours, and the Night shorter ; but the Difference is so small, that it may be neglected in this Matter.

*The Investi-  
gation of the  
Sun's entering  
the Æqua-  
tor.*

THE Moment of Time, in which the Sun enters the *Æquator*, is found out by Observation, and from the Latitude of the Place of the Observer. For in the Equinoctial Day, or near it, with an Instrument exactly divided into Degrees, Minutes, and Parts of Minutes, take the Meridian Altitude of the Sun : If it be equal to the Altitude of the *Æquator*, or to the Complement of the Latitude, the Sun is in that very Moment in the *Æquator* ; but if it is not equal, take the Difference and mark it, for it will be the Declination of the Sun. Then the next Day again observe the Meridian Altitude of the Sun, and gather from thence his Declination. If these two Declinations be of different Kinds, as the one South and the other North, the Equinox happens sometime between the two Observations, or if they be both of the same Sort, the Sun has either not entered the Equinoctial, or has past it. And from these two Observations of the Sun's Declination, the Moment of the Equinox is thus investigated.

Table XXII.  
Fig. 1.

LET CAB be a Portion of the Ecliptick, *ÆAQ* an Arch of the *Æquator*, and let their Intersection be in A. Let CÆ be the Declination of the Sun at the Time of the first Observation, ED his



his Declination in the second Observation, the Arch CE will be the Motion of the Sun in the Ecliptick for one Day. In the spherical Triangle AÆC right-angled at Æ, we have the Angle A, which the Æquator and the Ecliptick make, which we shewed how to find out in *Lecture XIX*; as also CÆ, the Declination of the Sun, known by Observation, by which we shall find the Arch CA. And in the same Manner in the Triangle AED the Side AE is found, and thence the Arch CE, which is the Sum or Difference of the Arches CA, AE. Say then, As CE is to CA, so is 24 Hours to the Time between the first Observation and the Moment of the Ingress of the Sun to the Æquinox.

IF again, the next Year, the Time of the Sun's Entry into the Æquator be observed in the same Manner, the Time elapsed between the two Ingresses is the Space of a *Tropical Year*, or the Time wherein the Sun, or rather the *Earth*, compleats its Course in the Ecliptick; which is called the *Tropical Year*, because after it is finished, all the Seasons return again in the same Order. But by Observations that are made at the Distance of a Year, we cannot safely rely upon the true Quantity of the Year collected from them; for a small Error of one Minute, being constantly encreased and multiplied by the Number of Years, in Process of Time would amount to a prodigious Mistake in the Place of the Sun. Therefore the *Astronomers* more accurately determine the Quantity of the Year, by taking the Observations of two Equinocties at many Years Distance from one another; and dividing the Time between the Observations, by the Number of Revolutions the Sun has made, the Quotient will shew the Time of one Revolution, or nearly the Period of the *Earth* in her Orbit. For by this Means, if there be any Mistake made in the Observation, it will be divided into so many Parts, according to the Number of Years, that it will be insensible for the Space of one Year.



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*The Ano-  
malistical  
Year.*

THE Space of Time belonging to the *Tropical Year*, is by this Means found to consist of 365 Days, 5 Hours, 48 Minutes, and 57 Seconds. This Time is somewhat less than the periodical Time of the *Earth* in her Orbit, which is called the *Anomalistical* or *Periodical Year*. For by reason of the Procession of the Equinocties, which was explained by us in the VIIIth *Lecture*, by which the Points of Intersection do constantly every Year move back 50 Seconds, and as it were, meet the Sun; the Sun will arrive at the Intersection before he has compleated his Course. Now the Time of the *Earth's* Period or *Anomalistical Year* is 365 Days, 6 Hours, 9 Minutes and 14 Seconds.

*The Motion  
of the Sun in  
the Ecliptick  
unequal.*

IF the Motion of the *Earth* round the Sun were equal, that is, if it described equal Angles round the Sun in equal Times, the apparent Motion of the Sun in the Ecliptick would always be equal, and would proceed each Day in the Ecliptick  $59' 8''$ : And therefore the Place of the Sun would easily be computed for any Time. But we are sure by Observation, that the apparent Motion of the Sun is not equal, and that he goes thro' some Parts of the Ecliptick quicker than thro' others; and particularly, in going thro' the Northern Semicircle of the Ecliptick, he spends near eight Days more than in passing over the Southern Semicircle; which ought to be performed precisely in the same Time, if the apparent Motion of the Sun were equal. Moreover, if we make Observations, and from them find out the Motion of the Sun in the Ecliptick for each Day; in some Days he will be found to move thro' the Space of 61 Minutes in a Day; at other Times he will scarcely be seen to have compleated 57 Minutes.

THE daily Motion of the Sun in the Ecliptick is observed in this Manner. Let CB represent the Ecliptick,  $\text{ÆQ}$  the  $\text{Æ}$ quator, whose common Intersection is in A: Take with an Instrument the Meridian Altitude of the Sun; the Altitude of the



the *Æquator* in the Place of Observation is likewise to be known: The Difference of these two Arches is the Declination of the Sun, which will therefore be known. Let *G* be the Place of the Sun in the *Ecliptick*, and *FG* his Declination. In the right-angled Triangle *GFA*, having the Side *FG* and the Angle *A*, we shall find the Arch *AG*, the Distance of the Sun from the Equinoctial Point; or his Longitude and Place in the *Ecliptick* at the Time of the Observation. The next Day again, observe the Meridian Altitude of the Sun, and find from thence his Declination, which suppose to be *ML*, from which, and the Angle *A*, by the same Method, we shall find out the Arch *MA*; from which subtract the Arch *AG*, and we shall have the Arch *GM*, which is passed through by the Sun in one Day. The bigness of this Arch is mutable, according to the Place the *Earth* has in its Orbit.

THE ancient *Astronomers*, who allowed no Mo-  
tions in the Heavens but what were circular and  
equal, that they might give an Account of this appa-  
rent Inequality of the Sun's Motion, imagined that  
the Sun moved round the *Earth*, or the *Earth*  
round the Sun, (for it is the same Thing which we  
suppose, to move, or stand still) in a circular Or-  
bit, but Eccentric; that is, whose Center was at  
some Distance from the Center of the *Ecliptick*,  
in which they placed either the Sun, or the *Earth*;  
and this circular Orbit, they supposed, was described  
by an equal Motion: And therefore, because the  
Center of the *Ecliptick* was at some Distance from  
the Center of equal Motion, the Motion of either  
the Sun, or *Earth*, seen from the Center of the *Ec-*  
*liptick*, would appear unequal.

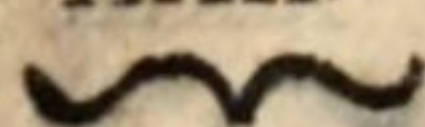
LET the Circle  $\Upsilon \text{ } \ominus \text{ } \equiv \text{ } \wp$  represent the *Eclip-*  
tick, in whose Center is the Sun. *MPNA* the  
Orbit of the *Earth*, whose Center is *C*, distant  
from the Center of the *Ecliptick* by the Line *CS*,  
which is called the Eccentricity. They supposed  
the *Earth* to move in this Circle with an equal Mo-  
tion: And therefore, all the Angles described round  
the Point *C*, would be proportional to the Times;  
and

The circular  
Hypothesis  
of the An-  
cients by  
which they  
explain'd  
the Appear-  
ances.

Table XXII,  
Fig. 2.



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and the *Earth* seen from C, would not appear to move slower in A than in P; but viewed from the Center of the Ecliptick, because at A it is farther distant than in P, it would appear to describe less Arches in equal Times: And therefore, when the *Earth* is in A, and a Spectator in it, observing the Sun in ☿, will find that he moves slower than when the *Earth* is in P, and the Sun is seen in ♄. And because the Arch of the Circle M A N is greater than a Semicircle, and N P M less than one; it is evident, that there is more Time required to describe the Arch N A M than N P M. But in the Time the *Earth* is carried through the Periphery N A M, the Sun seems to describe the Northern Semicircle of the Ecliptick, viz. ♈, ☊, ♎; and while the *Earth* is moving through the Arch M P N, the Sun will seem to have gone through the other, or the Southern Semicircle ♎, ♄, ♈. From hence the Reason is plain why the Sun stays longer in the Northern Signs than he does in the Southern.

The Determinations of the Eccentricity and Position of the Apfides on this Supposition.

UPON these Suppositions they thus determined the Eccentricity and Position of the *Apfides*. In the same Year observe the Moments of Time wherein the Sun enters both the Equinoctial Points, viz. the Vernal and Autumnal; as also, the Place of the Sun in the Ecliptick in any other intermediate Time; which suppose to be in ♊, the *Earth* being really in ♎. When the *Earth* is in the Point of its Orbit N, the Sun is seen in the Point ♈; then the *Earth* coming to L, the Sun appears in ♊; and when it has arrived in M, the Sun will be observed in ♎. Draw to the Place of the *Earth* in L the right Lines S L, C L. Let likewise C M, M N, and C N be joined; and let C M, and S L, cut one another in O. By Observations of the Places of the Sun, we have the Angle ♈ S ♊, as likewise its Complement to two right Angles ♎ S ♈. Also by the Distance of the Time between the Observations we have the Arch L M, or the Angle L C M, as also the Arch N A M, these being proportional to the Times; therefore we have likewise the Arch M P N, and the Angle M C N. In the Isosceles Triangle M C N,



M C N, having the Angle M C N, we have likewise the two Angles at the Base M and N: But in the Triangle M O S, we have the Angle M S O, and the Angle M: Therefore we have also the Angle M O S, and L O C which is vertical and equal to it. Suppose L C, the Radius of the Eccentrick, to consist of 100000 equal Parts, then in the Triangle L O C, having all the Angles, and the Side L C, we can find the Side O C. But we know M C, which is equal to L C; therefore we have M O. In the Triangle M O S we have all the Angles, and one Side M O, and therefore we shall have O S. Lastly, In the Triangle S O C, having S O and O C, and the Angle S O C, which is the Complement of the Angle S O M to two right Angles, we shall find S C the Eccentricity, and the Angle O S C; to which add the Angle M S O, and we shall have the Angle M S A, or the Arch  $\gamma \wp$ ; which shews the Position of the *Aphelion*, or its Distance from the Equinoctial Point  $\gamma$ .

By this Method, the Ancients found the Eccentricity to be 3450 of such Parts as the Radius of the Eccentrick was 100000; from which they easily calculated the Motion and Place of the Sun for any given Time, in the Manner following. In the Orbit of the *Earth*, let A P be the Line of the *Apfides*, and suppose the *Earth* at L describing its circular Orbit; the Arch A L, or the Angle A C L proportional to the Time, will be the *Earth's* mean *Anomaly*, as the Arch of the Ecliptick  $\wp \approx$ , or the Angle  $\wp S \approx$  is the true *Anomaly*. Having now the mean *Anomaly*, we have its Sine L Q, and its Co-sine C Q, to which add the known Eccentricity, and we shall have S Q. Say, as S Q is to L Q, so is the Radius to the Tangent of an Angle, which is Q S L; which therefore will be known. Or thus: In the Triangle S C L we have the Sides S C and C L, and the Angle S C L, the Complement of the mean *Anomaly* to two right Angles: Therefore we can find the Angle L S C, or L S A, the true *Anomaly*; for as  $CL + CS : CL - CS :: \text{Tangent of half the Angle L C A to a}$



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Fourth, which will be the Tangent of half the Difference of the Angles  $CSL$  and  $CLS$ : And because  $SC$  and  $CL$  are given and constant Quantities, the Difference of the Logarithms of  $CL + CS$  and  $CL - CS$  will be a constant Quantity; and if it be always subtracted from the Log. Tangent of half the Angle  $LCA$ , we shall have the Log. Tangent of half the Difference of the Angles  $CLS$  and  $CSL$ . But we have their Sum, and consequently the Angle  $LSA$  will be known; which shews the Place of the *Earth* in the Ecliptick, seen from the Sun; and the Point opposite is the Place of the Sun, seen from the *Earth*. In the first half Circle of Anomaly  $ALP$ , the mean Anomaly  $ACL$  is greater than the true Anomaly  $ASL$ . For the external Angle  $ACL$  is greater than the internal and opposite  $ASL$ : And if from the mean Anomaly  $ACL$  you take away the Angle  $CLS$ , there will remain the Angle  $LSC$ , the true Anomaly. In the second Semicircle of Anomaly, the mean Anomaly is less than the true. For suppose the *Earth* in  $R$ , the mean Anomaly is the Arch  $APR$ ; or, casting away the Semicircle, the Arch  $PR$ , or the Angle  $PCR$ : But the true Anomaly rejecting the Semicircle is  $PSR$ , which is equal to  $PCR$  and  $CRS$ . Therefore, if to the mean Anomaly we add the Angle  $CRS$ , we shall have the true Anomaly  $PSR$ , and the Place of the *Earth* in the Ecliptick. The Angle  $CLS$  or  $CRS$  is called the *Equation* or *Prosthaphæresis*; because sometimes it is to be added, sometimes to be subtracted from the mean Motion, that we may have the true Motion or Place of the *Earth*.

The Theory  
of the An-  
cients is not  
true.

THIS Theory of the Ancients answered well enough to the apparent Motions of the Sun, which were founded on Observations that were not very accurately made. But it was evident, from Observations of the other Planets, that their Motions could not be accounted for by such a Theory. And even in the Sun itself there is a *Phænomenon*, which is not to be explained by the Theory of the Ancients, but clearly overturns that Theory, and proves



proves it to be false, *viz.* By the most accurate Observations we find, that the apparent Diameter of the Sun, when he is in his *Apogæon*, is  $31' 29''$ ; in his *Perigæon*, it is  $32' 33''$ ; but the apparent Diameters are reciprocally as the Sun's Distances. From whence we find, that the true Distance in the *Apogæon* is to the Distance in the *Perigæon*, as 1953 is to 1889, or as 101661 is to 98339; so that the Eccentricity is but 1661 of such Parts, whereof the Radius of the Eccentrick is 100000. The Theory of the Ancients makes the Eccentricity above double of this. And therefore that Theory must be false, which supposes so great an Eccentricity: For if we should allow but one Half for the Eccentricity, that would better answer to the apparent Diameters of the Sun, when they are nicely observed: But then, on the other Hand, so small an Eccentricity would not account for the Inequalities of the Sun's Motion, making the Center of the Eccentrick the Center of the middle Motion; for by computing, we find the *Equations* or *Prosthaphæreses* twice as great as what they would amount to with half only of the Eccentricity of the Ancients: And therefore it is plain, that this Theory of the Ancients must be false.

THE sagacious *Kepler*, observing this, shewed that the Eccentricity was indeed to be bisected; but so, that the Center of the Eccentrick was in D, in the middle Point between the Sun and the Point C; from which C, if the Motion of the *Earth* were viewed, it would appear equal. This Point C, which was distant from the Center of the Eccentrick by half the Eccentricity of the Ancients, was called the Center of the middle Motion; because from it the Motion of the *Earth* would always be seen in a mean Motion between its quick and slow Progress in the *Ecliptick*.

'Tis true, *Copernicus*, and many other *Astronomers*, thought it absurd to suppose the *Earth* carried in a Circle, whose Center was not the Center of the equal Motion; for then the *Earth's* Motion must not only be in Appearance, but really in itself unequal; and in some Parts of the Periphery of its Orbit it



Lecture XXII. would move faster, in other slower, contrary to their establish'd Maxim, of having all the Motions perfectly uniform.

Kepler's  
Elliptick  
Theory.

There are  
no Centers  
of middle  
Motion.

Kepler's  
Theory  
esteemed un-  
geometrical.

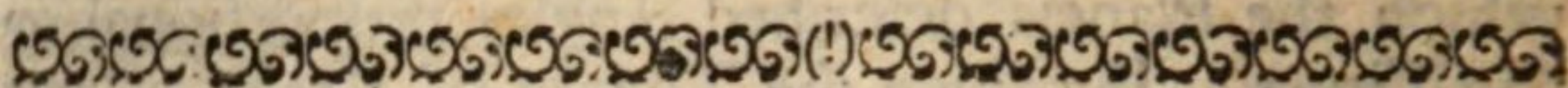
BUT *Kepler*, when he had demonstrated that *Mars*, and the other Planets, were not carried round the Sun in circular, but in elliptical Orbits; and that the Sun was in one of the *Foci* of those Ellipses; and that the Planets, in moving round him, did so regulate their Motions, that a Line or Ray drawn from the Sun to the Planet, did sweep an *Elliptick Area* or Space, always proportional to the Time the Planet moved, he thought it but reasonable to suppose the *Earth*, in turning round the Sun, should observe the same Law, and be carried likewise in an elliptick Orbit. This Theory answers exactly to all Appearances; but it follows from it, that there are no Centers of equal, or middle Motion, from which the Planets can be seen to describe Angles proportional to the Times. And therefore many *Astronomers*, still adhering to the Opinion that there were Centers of equal Motion, rejected this Theory of *Kepler's*; but for all that, they retained the elliptick Form of the planetary Orbits. And because in the Axis of an Ellipse there are two Points equally distant from the Center, which are called the *Foci*, in one of which, they, with *Kepler*, placed the Sun; the other, which was distant from the Sun the double of the Eccentricity, they imagined to be the Center of equal Motion, and round it they suppos'd the Planets to describe Angles proportional to the Times; which, indeed, in Ellipses, that are not very eccentric, is nearly true, as *Kepler* himself acknowledges, and we shall hereafter demonstrate. This Hypothesis they liked the better, because there was no direct or geometrical Method in the Theory of *Kepler*, to find out the true Anomaly from the Mean; which, by the other Theory, they could easily find. Upon the Account of this Deficiency of Method, many *Astronomers* objected to *Kepler* ἀνεωκυστία, or want of Geometry in his Theory; and rejecting it, went upon other Hypotheses, which did not so well agree with the true Laws of Nature; and



and they feigned, that in each Orbit there was a certain Point for the Center of equal Motion, round which the Planets described Angles proportional to the Times : But since the Theory of *Kepler* is that which does really obtain, and only has Place in Nature ; and all Observations declare, that the Planets do really regulate their Motions by its Laws ; it is not to be rejected upon the Account of a Want in *Geometry*, nor is the Fault to be laid upon the Theory, which is rather to be imputed to the Unskilfulness of the *Astronomers* in *Geometry*. We therefore, that we may remove this Blemish of want of *Geometry* for the future, in the following *Lecture* will shew a direct Method of finding the true Anomaly of a Planet, from its mean Anomaly given.







## LECTURE XXIII.

*Of the Motion of a Planet in an Ellipse,  
and the Solution of Kepler's Problem  
about the cutting of the Elliptick  
Area.*



THE Great Kepler was the first who demonstrated, that the Planets did not move in circular Orbits, but that they were carried round the Sun in elliptical ones; all which had one common *Focus*, in which the Sun resided: and that the Planets, in their Motions, constantly observed a certain Law, viz. that a Ray or Line, reaching from the Sun to the Planet, did sweep elliptical Spaces that were proportional to the Times.

By Kepler's  
Theory  
Sir Isaac  
Newton  
found out the  
physical  
Causes of  
the Planets  
Motions.

The Proportion of the  
Planets periodical  
Times to their  
Distances  
found out  
by Kepler.

THIS admirable and divine Invention of the sagacious Kepler, was owing to the exact Observations of *Tycho Brahe*; and is so much more to be valued, for that by the Help of it, the most incomparable *Philosopher* Sir Isaac Newton discovered the universal Laws of Motion, the System of the Universe, and the whole Body of the Celestial Philosophy, which was intirely unknown before. Kepler also demonstrated, from Observations of the Motions, that in all the Planets their periodical Times were in a sesquiplicate Proportion of their mean Distances from the Sun, or of the greater Axis of the Ellipses, which are equal to twice the mean Distances; that is, the Squares of the periodical Times are constantly as the Cubes of the greater Axes: And therefore, if in two different



erent Ellipses the greater Axes be called  $A, a$ , Lecture  
 their periodical Times  $T$  and  $t$ ; then we shall XXIII.  
 have their Analogy  $T^2 : t^2 :: A^3 : a^3$ , and  $T : t ::$   
 $A^{\frac{3}{2}} : a^{\frac{3}{2}}$ .

HENCE it follows, that in different Ellipses, the  
 Area's, described by two Planets in the same Time,  
 are in subduplicate Proportion of the Parame-  
 ters or *Latera recta* of the Ellipses; which I thus  
 prove. It is known from the Property of the  
 Ellipse, that its Area is as the Rectangle under  
 the two Axes of it; that is, if the two Axes  
 of the greater Ellipse be called  $A$  and  $M$ , and  
 the two Axes of the smaller Ellipse be called  $a$   
 and  $m$ ; the Area of the greater Ellipse will be  
 to the Area of the lesser, as  $A \times M$  is to  $a \times m$ .  
 And therefore, when we are speaking of the Pro-  
 portion of the Area's, we may put these Rectan-  
 gles instead of the Area's. In the greater Ellipse  
 call the Area described in a given Time  $X$ , the  
 Area described in the lesser Ellipse in the same  
 Time  $x$ , and the Time given in which they are  
 described  $y$ ; the *Latera recta* of the Ellipses call  
 $L$  and  $l$ , the periodical Times  $T$  and  $t$ . From  
 the Theory above explained it follows, that  
 $X : A \times M :: y : T$ , also that  $a \times m : x :: t : y$ .  
 And therefore, by Equality of Proportion, 'twill  
 be  $X \times a \times m : x \times A \times M :: t : T :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$ . But  
 since the lesser Axis is a mean Proportional between  
 the greater Axis and the *Latus rectum*,  $M$  will  
 be  $= A^{\frac{1}{2}} \times L^{\frac{1}{2}}$ , and  $m = a^{\frac{1}{2}} \times l^{\frac{1}{2}}$ . And therefore,  
 $X \times a^{\frac{3}{2}} l^{\frac{1}{2}} : x \times A^{\frac{3}{2}} L^{\frac{1}{2}} :: a^{\frac{3}{2}} : A^{\frac{3}{2}}$ . And therefore,  
 $X \times l^{\frac{1}{2}} : x \times L^{\frac{1}{2}} :: 1 : 1$ ; that is, in Proportion of  
 Equality: And therefore,  $X : x :: L^{\frac{1}{2}} : l^{\frac{1}{2}}$ . And  
 therefore, in different Ellipses, the Area's described  
 in the same Time, are as the square Roots of their  
*Latera recta*.

SINCE therefore the Law, by which the Pla-  
 nets regulate their Motions, is the equal or uni-  
 form



Lecture XXIII. form Description of the Area's, it is impossible that the Planets can every where move with the same uniform Velocity, but it must constantly be changed: So that going from the *Perihelion* to the *Aphelion*, they must constantly slacken their Pace;

*The Velocity every where reciprocal to the Squares of their Distances.* but as they descend from the *Aphelion* to the *Perihelion* they must again quicken their Motions: And in the *Aphelion* they have the slowest, in the *Perihelion* the quickest Motion: And the Velocity will be every where reciprocally as a Perpendicular that falls upon a Right Line passing through the Planet and touching the Orbit. Let D A F

Plate XXII.  
Fig. 3.

be an Ellipse, whose *Focus* is S; and suppose the Arches A B, *a b* thereof to be gone over by the Planet in equal Times that are exceeding small, the Triangles S A B and S *a b* will be equal; for they are the Area's that the carrying Ray describes in equal Times. From the *Focus* S let fall on the Tangents the Perpendiculars S P, S *p*, and the Triangle S A B will be equal to  $\frac{1}{2} S P \times A B$ : So likewise the Triangle S *a b* will be equal to  $\frac{1}{2} S p \times a b$ : And therefore  $S P : S p :: a b : A B$ : But A B and *a b*, since they are Lines described in the same Time, are as the Velocities: Wherefore the Velocity in A is to the Velocity in *a*, as S *p* is to S P, the Perpendicular. Mr. De Moivre, in the *Philosophical Transactions*, No 352, has likewise demonstrated the two following Theorems concerning the Elliptick Motion.

### THEOREM I.

A Theorem to determine the Proportion of the Velocity.

Tab. XXVI  
Fig. 7.

LET *A P B* be the elliptick Orbit, in which suppose a Planet to move round the Sun in the Focus S. Let C be the Center of the Ellipse, C B half the greater Axis, C D half the lesser, and F the other Focus. The Planet being in P, draw the right Lines S P, F P; then the Velocity of the Planet in P, will be to the Velocity in its mean Distance S D, in a subduplicate Proportion of its Distance F P from the Focus F, to its Distance S P from the Focus S.

LET the right Line E P G touch the Ellipse in P, and from each of the Foci on the Tangent let fall



fall the Perpendiculars  $SE$ ,  $FG$ ; and let  $SH$  be a Perpendicular on the Tangent  $DH$ . The Velocity in  $P$  is, as we have shew'd, to the Velocity in  $D$ , as  $SH$  is to  $SE$ ; And therefore the Square of the Velocity in  $P$  is to the Square of the Velocity in  $D$ , as  $SH$  square or  $CD$  square to  $SE$  square; that is, by the Nature of the Ellipse (because  $CD$  square is equal to  $SE \times FG$ ) as  $SE \times FG$  is to  $SE$  Square, or as  $FG$  to  $SE$ . But because of the equiangular Triangles  $FG$  is to  $SE$ , as  $FP$  is to  $SP$ : Wherefore the Square of the Velocity in  $P$ , is to the Square of the Velocity in  $D$ , as  $FP$  is to  $SP$ : And consequently, the Velocity in  $P$ , is to the Velocity in  $D$ , as  $\sqrt{FP}$  is to  $\sqrt{SP}$ , which was to be demonstrated.

## THEOREM II.

THE Radius is to the Sine of the Angle  $SPE$  as  $\sqrt{SP \times FP}$  to  $CD$ . For  $SP$  square is to  $SP \times FP :: SP : FP :: SE : FG :: SE$  square;  $SE \times FG :: SE$  square:  $CD$  square. And by Alternation of Proportion  $SP$  square:  $SE$  square ::  $SP \times FP : CD$  square: And therefore,  $SP : SE :: \sqrt{SP \times FP} : CD$ : But  $SP : SE ::$  Radius is to the Sine of the Angle  $SPE$ . Therefore as the Radius is to the Sine of the Angle  $SPE$ , so is  $\sqrt{SP \times FP}$  to  $CD$ , which was to be demonstrated.

WE have already shewed the Proportion by which the absolute Velocity increases or decreases: But we have another Theorem for determining the angular Velocity, or the Angle which a Planet, seen from the Sun, will appear to describe in a small Particle of Time: For it is every where reciprocally in a duplicate Proportion of the Distance from the Sun: which I thus demonstrate.

At the Center  $S$ , at the Distances  $SB$ ,  $Sb$  describe the small Arches  $BE$ ,  $be$ , where  $AB$ ,  $ab$  are the small elliptick Arches described in equal Times:

In

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XXIII.

The angular  
Velocity at  
the Sun is as  
the Square  
of their Di-  
stances reci-  
procally.

Plate XXII.  
Fig. 3.



Lecture XXIII. In  $SB$  take  $Sm$  equal to  $Sb$ , and draw the small Arch  $mn$ : And the angular Velocity in  $b$  is to the angular Velocity in  $B$ , as the Arch  $be$  is to the Arch  $mn$ : But the Proportion of  $be$  to  $mn$  is compounded of the Proportion of  $be$  to  $BE$ , and of  $BE$  to  $mn$ . And because the Triangles  $BSA$  and  $bSa$  are equal,  $be$  will be to  $BE$  as  $SB$  is to  $Sb$ : And because the Arches  $BE$  and  $mn$  are similar,  $BE$  is to  $mn$  likewise, as  $SB$  to  $Sm$ , or as  $SB$  to  $Sb$ : Wherefore the Proportion of  $be$  to  $mn$  is compounded of the Proportion of  $SB$  to  $Sb$ , and again of  $SB$  to  $Sb$ ; that is, the angular Velocity at  $b$  is to the angular Velocity at  $B$ , as the Square of  $SB$  is to the Square of  $Sb$ , that is, reciprocally as the Squares of the Distances.

*The Angular Velocity of a Planet compared with an equal Velocity of a body moving in a Circle.* BUT to explain more clearly the Inequality of the Planets Motions, and the various Increase and Decrease of their angular Velocities, it will be requisite to compare their Motions in different Points of their Orbit, with an equal and uniform Motion of a Body moving in a Circle.

Plate XXII.  
Fig. 4.

Let therefore the Ellipse  $AEBF$  be the Orbit of a Planet in whose *Focus* is the Sun  $S$ . Its greater Axis  $AB$ , and lesser  $OQ$ . At the Center  $S$  and Distance  $SE$ , which is a mean Proportional between  $AK$  and  $OK$ , the two Semiaxes, describe the Circle  $CEGF$ . The Area of this Circle will be equal to the Area of the Ellipse, as it is easily to be demonstrated from the Nature of the Ellipse: And let us suppose a Point to move with an uniform or equal Motion thro' the Periphery  $CEGF$ , in the same Time that the Planet describes the Ellipse: And when the Planet is in its *Aphelion*  $A$ , let the circulating Point be in  $C$ , in the Line of the *Apsides*. The Motion of this Point will represent the equal or middle Motion of the Planet, and the Point will describe round  $S$  Areas, or Sectors of Circles, which are proportional to the Times, and equal to the elliptick Areas the Planet at the same Time describes. Let now the equal Motion or the Angle round  $S$  proportional



portional to the Time be  $CSM$ ; and take the Area  $ASP$ , equal to the Sector  $CSM$ ; and then the Place of the Planet in its own Orbit will be  $P$ , and the Angle  $MSD$ , the Difference between the true Motion of the Planet and its mean Motion, is the Equation or *Prosthaphæresis*: And the Area  $ACDP$  will be equal to the Sector  $DSM$ , and consequently, proportional to the *Prosthaphæresis*; and consequently, where this Area is biggest, there the *Prosthaphæresis*, or the Equation, will be biggest: But the Area is biggest in the Point  $E$ , where the Circle and the Ellipse cut each other. For when the Planet descends further to  $R$ , the Equation becomes proportional to the Difference of the Areas  $ACE$  and  $mER$ , or to the Area  $GBRm$ . For when the Planet is in  $R$ , let  $V$  be the Place of the Point moving uniformly in the Circle, the Sector  $CSV$  will be equal to the Elliptick Area  $ASR$ : And taking away the common Spaces, the Area  $ACE$  less the Area  $REM$  is equal to the Sector  $VS m$ , or to the Equation.

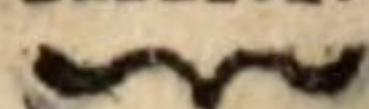
*The Area proportional to the Prosthaphæresis.*

*Where the Equation is greatest.*

IN the *Perihelion* the equal Motion and the true Motion of the Planet coincide; for the Semicircle  $CEG$  is equal to the Semi-ellipse  $AEB$ . But after the Planet departs from the *Perihelion*  $B$ , its Motion is constantly quicker, and it goes before the Point moving equally with the mean Motion. For let the Angle  $GSZ$  be proportional to the Time, take the Area  $BSY$ , equal to the Sector  $GSZ$ , and  $Y$  will be the Place of the Planet in its Orbit; and the Angle  $BSY$  will be greater than the Angle  $GSZ$ ; and the Area  $GBYL$  will be equal to the Sector  $ZSL$ , whose Angle is the Equation: And where the Area  $GBYL$  is greatest, there the Equation is greatest; that is, in the Point  $F$ , where the Circle and Ellipse cut one another. In  $A$  the Velocity of the Planet is the least of all, because the Distance  $SA$  is the greatest; from thence the Planet descending to its *Perihelion*, its Velocity will constantly increase; but it will still be less than the mean Velocity, till it comes to  $E$ , the Intersection of the Ellipse



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XXIII.



Ellipse and Circle: And there its Velocity becomes just equal to the mean; which I thus prove. When the Planet is in E, let the Point going with the equal or mean Velocity be in  $m$ , and the Areas described round S, in the same infinitely small Time, be  $nSE$ , and the Sector  $iSm$ , which will be equal. And therefore  $bE \times ES$  is equal to  $im \times ms$ : And therefore, because  $Sm$  and  $SE$  are equal,  $bE$  and  $im$  must be equal; and the Angle  $nSE$  will be equal to the Angle  $iSm$ . At the Point therefore E, the angular Velocity of the Planet is equal to its mean Velocity; the Planet going from E, and approaching still nearer to its *Perihelion*, the Velocity grows bigger than the mean Velocity; and its Distance from the Sun being constantly decreasing, the Velocity will continually increase, till it comes to the *Perihelion*, where it is the greatest of all, because the Distance  $SB$  is the least of all. The Planet departing from thence, and ascending to the *Aphelion*, it leaves the Point, which proceeds constantly with the middle Motion, behind it; but as it goes farther off from the Sun, its Velocity decreases, but is still bigger than the mean Velocity, till it comes to F, the Point of Intersection of the Ellipse and the Circle, where the Planet's angular Velocity is again equal to the mean angular Velocity; and when it has passed that Point, its Velocity becomes less than the mean, and constantly diminishes till it arrives at the *Aphelion*, where it is the least of all; its Distance from the Sun being then greatest of all.

SINCE therefore each Planet in different Parts of its Orbit has different Degrees of Velocities, and the only Equality which is observed in its Circulation round the Sun, is the equal Description or Increase of the elliptick Area, which grows bigger uniformly with the Time; to determine the Place of a Planet in its Orbit at any given Time, we must take an elliptick Area that is proportional to the Time. And to do this, it is necessary to solve the following *Problem*.

KEP-



## KEPLER'S PROBLEM.

*To find the Position of a Right Line, which passing through one of the Foci of an Ellipse, shall cut off an Area described by its Motion, which shall be to the whole Area of the Ellipse in a given Proportion.*

LET the Ellipse be  $APB$ , whose *Focus* is  $S$ . I Tab. XXII. Fig. 5.  
 must find the Position of the Right Line  $SP$ , which cuts off the trilineal Area  $ASP$ , to which the whole Area of the Ellipse has the same Proportion that the periodical Time of the Planet has to any other given Time; which Position being found, we shall have the Place the Planet is in at the given Point of Time. Or let  $AQB$  be a Semicircle, described on the greatest Axis of the Ellipse; we must draw from  $S$  the Line  $SQ$ , which shall cut off the Area  $ASQ$ , to which the Area of the whole Circle is in the above-mention'd Proportion. For by such a Section of a Circle, the Section of the Ellipse is easily found out, by letting fall from the Point  $Q$  a Perpendicular on the Axis  $AB$ ; which will cut the Ellipse in the Point  $P$  required, to which draw the Line  $SP$ , and it will be the Right Line which divides the Area of the Ellipse in the given Proportion; so that  $P$  will be the Place of the Planet: For the elliptick Segment  $APH$  is to the circular Segment  $AQH$ , as  $HP$  is to  $HQ$ ; that is, as the Area of the whole Ellipse is to the Area of the whole Circle, as is known from the Nature of the Ellipse: But the Triangle  $SPH$  is to the Triangle  $SQH$ , in the very same Proportion by *Prop. 1. El. VI.* And therefore, by *Prop. 12. El. V.* the elliptick Area  $ASP$  is to the circular Area  $ASQ$ , as the Area of



Lecture of the whole Ellipse is to the whole Circle: And, XXIII. by Alternation, the Area ASP is to the whole Ellipsis, as the Area ASQ is to the Circle. Hence, if we have a Method of drawing thro' S a Line which will cut the Area of the Circle in a given Proportion, it will be easy to cut the Area of the Ellipse in the same Proportion.

The Anomaly of the Eccentrick.

KEPLER, who first proposed the *Problem*, knew no direct Method of computing the Planet's Place from the Time; and expressly tells us, that there was no direct Way of finding, from the Time given, the true Anomaly of the Planet, or its Place in its Orbit. And therefore he found it necessary to go through every Degree of the Semi-circle AQB; and to search from the Arch AQ, which he called the *Anomaly of the Eccentrick*, the Time which was expressed by the Area ASQ, which is proportional to the mean Anomaly; as also the Angle ASP, which gives the true Place and true Anomaly of the Planet, which he computed by Calculation. And therefore, because he could not directly and geometrically solve the *Problem*, some *Astronomers* objected to him an *ἀγνοῖα* or want of *Geometry*; and that he was so fond of physical Causes, that he had departed from *Geometry*; and they blamed his *Astronomy*, as not being geometrical, since it was founded on such a Theory. And therefore, that they might escape the committing of such a Fault, they went upon other *Hypotheses*, and feigned a Point, round which the Planets Motion should be equal, or the Angles proportional to the Times: And from thence, the mean Anomaly being given, they calculated the true Place of the Planet. But the Calculations founded on these *Hypotheses* were found not to answer Observations: For there is really no fixed Point which is the Center of equal Motion, round which the Planets describe Angles proportional to the Times: And the only Theory, that answers all Observations, is that above-explained of *Kepler*. And therefore, the *Astronomers* must now for ever embrace this Theory of *Kepler*, since it

not



not only agrees perfectly with the Motions of the Heavens; but also lays most elegantly open the Cause and Source of all those Motions. *Kepler* himself valued this Theory so much, that he chose rather to take up with an indirect Method of Calculation, than contrive another *Hypothesis* that was not agreeable to the Nature of Things; and for this the ablest Judges were not displeased with him. Therefore to take away this Blemish of want of *Geometry* out of our *Astronomy*, we will here shew a direct Method by which the Area of an Ellipse, or of a Circle, which is equivalent, may be cut in a given Proportion.

LET  $AQB$  be a Semicircle whose Diameter is the greater Axis of the Ellipse, its Center  $C$ , and  $S$  the *Focus* of the Ellipse in which the Sun is placed. Thro' the Place of the Planet imagine a Perpendicular  $QH$  to be drawn to the Axis, meeting with the Circle in  $Q$ : Then the Area  $ASQ$  will be to the whole Circle as the given Time is to the periodical Time of the Planet. Draw  $CQ$ , and from  $S$  let fall upon it, produced if required, the Perpendicular  $SF$ : The Area  $ASQ$  is equal to the Sector  $ACQ$  and the Triangle  $QSC$ ; that is, equal  $\frac{1}{2} QC \times AQ + \frac{1}{2} QC \times SF$ . And therefore, because  $\frac{1}{2} QC$  is a constant Quantity, the Area  $ASQ$  will be always proportionable to the Arch  $AQ$  + the right Line  $SF$ , when the Motion is from the *Aphelion* to the *Perihelion*: But when the Planet ascends from the *Perihelion* to the *Aphelion*, the Area  $BSq$  is equal to the Sector  $BCq$  — Triangle  $CSq$ : And therefore it will be proportional to the Arch  $Bq$  — the right Line  $Sf$ . Hence, if we take the Arch  $AN$  or  $Bn$  proportional to the Time,  $AQ + SF$  will be equal to  $AN$ , or  $Bq - Sf = Bn$ ; for then  $AN$  and  $Bn$  will be proportional to the Area's  $ASQ$  and  $BSq$ .

HENCE, if we have the Arch  $AQ$ , and add to it the Arch  $QN$ , which is equal to the right Line  $SF$ ; the Arch  $AN$  will be proportional to the Time, or equal to the mean Anomaly



Lecture of the Planet; and therefore, if we have the true  
 XXIII. Anomaly of a Planet, we may easily find the Mean,  
 or the Time. For let  $QC$  be to  $SC$  as 57,29578  
 (which Number expresses the Length of an Arch in  
 Degrees and Parts of a Degree that is equal to the  
 Radius) to a fourth Number; and we shall have an  
 Arch equal to  $SC$  in Degrees and decimal Parts.  
 Call this Arch  $B$ ; and because  $SC$  is to  $SF$ , as the  
 Radius is to the Sine of the Angle  $SCF$  or  $ACQ$ ,  
 say, as the Radius is to the Sine of  $ACQ$ , so is the  
 Arch  $B$  to a Fourth; and then we shall have, in De-  
 grees and decimal Parts, an Arch in the Periphery  
 $AQB$ , which is equal to the right Line  $SF$ : And  
 because  $SF$  is equal to  $QN$ , we have the Arch  
 $QN$ , and also the Arch  $AN$ , which is propor-  
 tional to the Time.

LET us explain this by Examples in the Orbit  
 of *Mars*. The Eccentricity of this Orbit is to its  
 mean Distance as 14100 is to 152369. And there-  
 fore the Logarithm of the Arch  $B$ , which is equal  
 to  $SC$  is 0,7244446: And therefore, if we would  
 have the mean Anomaly, when the Anomaly of  
 the Eccentrick is one Degree, add the Log. Sine of  
 1 Degree to the Log. of  $B$ , the Sum is 8,9662999.  
 This being the Log. of the Number 0,092533,  
 expresses the Length of the Arch  $QN$  in decimal  
 Parts of a Degree. And therefore the Arch  $AN$ ,  
 or the mean Anomaly, is 1,092533 or  $1^{\circ} 5' 33''$ .  
 In like Manner, if the Anomaly of the Eccentrick  
 be  $30^{\circ}$ , to its Log. Sine add the constant Log. of  
 $B$ ; and the Sum will be 0,4234146; which is  
 the Log. of the Number 2,651; and therefore the  
 mean Anomaly  $AN$  answering to 30 Degrees of  
 the Eccentrick Anomaly, is 32,651, or  $32^{\circ} 39' 3''$ .  
 This Method is much quicker and easier than that  
 which *Kepler* gives; where, by an indirect Method,  
 and the Rule of false Position, he shews how to  
 compute the true Anomaly from the Mean.

LET us now come to the Method I promised  
 of directly finding the true Anomaly from the  
 Mean. In the Figure, let the Arch  $AN$  be the  
 mean Anomaly, or proportional to the Time;

AQ



AQ the Anomaly of the Eccentric which is to be found. Call the Arch NQ  $y$ , and the Sine of AN call  $e$ , and Co-sine  $f$ ; and let the Eccentricity SC be  $g$ . The Sine of the Arch AQ is equal to the Sine of the Arch AN — NQ, equal to the Sine of the Arch AN —  $y$ . But we have demonstrated in the Elements of *Trigonometry*, that if the Sine of the Arch AN be  $e$ , the Sine of the Arch

AN —  $y$ , or of AQ, will be  $e - \frac{fy}{1} - \frac{ey^2}{1.2} + \frac{fy^3}{1.2.3}$

$+ \frac{ey^4}{1.2.3.4}$  &c. But the Radius which is 1, is to the Sine of the Arch AQ, as SC or  $g$  is to SF or

NQ; that is to  $y$ : And therefore  $y = ge - \frac{gfy}{1}$

$- \frac{gey^2}{1.2} + \frac{gfy^3}{1.2.3} + \frac{gey^4}{1.2.3.4}$  &c. And therefore we

have  $ge = y + \frac{gfy}{1} + \frac{gey^2}{1.2} - \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}$

&c. Let  $ge = z$ , and  $1 + fg$  call  $a$ ,  $\frac{ge}{2} = b$ ,

$\frac{gf}{1.2.3} = c$ ; and  $\frac{ge}{1.2.3.4} = d$ . And the Equation

will be in this Form  $z = ay + by^2 - cy^3 + dy^4$  &c. And therefore, by the Method of Reversion of Series, invented by Sir ISAAC NEWTON,

we have  $y = \frac{z}{a} - \frac{bz^2}{a^3} + \frac{2b^2 + ac}{a^5} z^3$

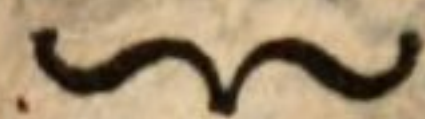
$- \frac{5abc - 5b^3 + a^2d}{a^7} z^4$  &c. But because

$b = \frac{ge}{2} = \frac{z}{2}$  and  $d = \frac{z}{24}$ , we shall have  $y = \frac{z}{a}$

$- \frac{z^3}{2a^3} + \frac{cz^3}{a^4} - \frac{5cz^5}{2a^6}$  &c. But if the Arch AN

be greater than 90 Degrees, and less than 270, then  $ge$   
U 2 or



Lecture  
XXIII.

$$\text{or } z = y = gfy + \frac{gey^2}{2} + \frac{gfy^3}{1.2.3} - \frac{gey^4}{1.2.3.4}. \text{ And}$$

$$\text{then } a = 1 - gf, \text{ and } y = \frac{z}{a} - \frac{z^3}{2a^3} - \frac{ez^3}{a^4} \&c.$$

This Series expreffes the Arch QN, the Parts whereof the Radius is 100000: But to have it in Degrees, and Parts of a Degree, fay, as the Radius is to this Series, fo is 57.29578, which are the Degrees of an Arch equal to the Radius, to a Fourth; consequently, fince the Radius is Unity, if we multiply the Series by 57.29578, which Number call R, we fhall have the Arch y in Degrees and deci-

$$\text{mal Parts} = \frac{Rz}{a} - \frac{Rz^3}{2a^3} + \frac{Rcz^3}{a^4}, \&c. \text{ The very}$$

first Term of this Series  $\frac{Rz}{a}$  is fufficient to determine the Anomaly of the Eccentrick in almost all the Planets, nearly enough. For in *Mars*, the Error feldom exceeds the 200th Part of a Degree; in the *Earth* it is lefs than the 10000th Part of a Degree. But it will be beft to fhew the Ufe of this Method by Examples.

IN the Earth's Orbit the Eccentricity is 0,01691, when the mean Distance CQ is 1. Suppose we are to find the Anomaly of the Eccentrick, and the equated Anomaly when the mean Anomaly is 30 Degrees.

|                             |   |           |
|-----------------------------|---|-----------|
| The Log. of Eccentricity is | — | 8,2281436 |
| The Log. Sine of 30°        | — | 9,6989700 |
| The Log. of R               | — | 1,7581226 |

|                        |   |           |
|------------------------|---|-----------|
| The Log. of Rz         | — | 9,6852362 |
| The Log. of a fubtract | — | 0,0063137 |

|                        |   |           |
|------------------------|---|-----------|
| The Log. of the Arch y | — | 9,6789225 |
|------------------------|---|-----------|

To which answers the Number 0,47744, or in fexagesimal Numbers 28' 38": The reft of the Terms don't amount to the 10000th Part of a Degree, and may therefore be neglected. If therefore from 30 Degrees we deduct 28' 38", we fhall have



have the Arch  $AQ$   $28^{\circ} 31' 22''$ . In the Triangle  $QCS$ , we have the Sides  $QC$ ,  $CS$ , and the Angle  $SCQ$ : Wherefore we shall have the Angle  $QSC$ . The Analogy is  $QC + CS$ , or  $AS$  :  $QC - CS$ , or  $BS$  :: Tangent  $\frac{CSQ + CQS}{2}$  :

Tangent of  $\frac{CSQ - CQS}{2}$ . Therefore, if from the Tangent of half the Angle  $ACQ$  we subtract a constant Log.  $0,0146893$ , we shall have the Tangent of an Angle, which, added to half the Angle  $ACQ$ , gives the Angle  $CSQ$ , or  $ASQ$ , which in the present Case, is  $29^{\circ} 3' 7''$ . But to find the Angle  $ASP$ , we must diminish the Tangent of the Angle  $ASQ$ , in the Proportion of the bigger Axis of the Ellipse, to its lesser. Therefore, from the logarithmick Tangent of  $ASQ$ , take away the constant Log.  $0,0000622$ , which is the Log. of the *Ratio* of the greater Axis to the less, and we shall have the Log. Tangent of the Angle  $ASP$ ; which Angle is equal to  $29^{\circ} 2' 54''$ . And this is the equated Anomaly. Plate XXII.  
Fig. 5.

In the Orbit of *Mars*, the Eccentricity is 14100 of such Parts as the mean Distance is 152369. And therefore, the Log. of the *Ratio* of  $SC$  to  $CQ$ , is  $8,9663226 = \text{Log. of } g$ . Let us find the Anomaly of the Eccentrick, when the mean Anomaly is 1 Degree.

|                          |   |           |
|--------------------------|---|-----------|
| The Log. of Eccentricity | — | 8,9663226 |
| The Log. Sine of 1 Deg.  | — | 8,2418453 |
| The Log. of R            | — | 1,7581220 |

|                          |   |           |
|--------------------------|---|-----------|
| The Log. of $Rz$         | — | 8,9662899 |
| The Log. of $a$ subtract | — | 0,0384299 |

|                            |   |           |
|----------------------------|---|-----------|
| The Log. of $\frac{Rz}{a}$ | — | 8,9278600 |
|----------------------------|---|-----------|

First, THE Number answering this Log. is  $0,084697$ , and gives the Bigness of the Arch  $NQ$ , and the Error is less than the 30000th Part of a Degree.



Lecture XXIII. *Secondly*, SUPPOSE the mean Anomaly is 45 Degrees, and I am to find the Anomaly of the  Eccentrick.

|                          |           |
|--------------------------|-----------|
| The Log. of Eccentricity | 8,9663226 |
| The Log. Sine of 45°     | 9,8494850 |
| The Log. of R            | 1,7581220 |

|                        |           |
|------------------------|-----------|
| The Log. of R z        | 0,5739296 |
| The Log. of a subtract | 0,0275249 |

|                             |           |
|-----------------------------|-----------|
| The Log. of $\frac{R z}{a}$ | 0,5464047 |
|-----------------------------|-----------|

To which answers the Number 3,5189, which is more than the Truth, by about 150th Part of a Degree: And to correct this Error, take the second

Term of the Series —  $\frac{R a + 2 R c \times z^3}{2 a^4}$ , which

will be found equal to the Fraction 0,0065, and subtract this from the first, there will remain 3,5124, which expresses the Arch NQ true to the 100000th Part of a Degree.

*Thirdly*, LET us find out the Anomaly of the Eccentrick, when the mean Motion is 100 Degrees: In this Case  $a = 1 - g f = 0,983930$ .

|                                  |           |
|----------------------------------|-----------|
| The Log. Eccentricity, or of g   | 8,9663226 |
| The Log. Sine of 100°, or of 8c° | 9,9933515 |
| The Log. of R                    | 1,7581220 |

|                        |           |
|------------------------|-----------|
| The Log. of R z        | 0,7177961 |
| The Log. of a subtract | 9,9929598 |

|                             |           |
|-----------------------------|-----------|
| The Log. of $\frac{R z}{a}$ | 0,7248363 |
|-----------------------------|-----------|

The Number answering to this Log. is 5,3068, which is greater than the Truth, by about the 50th Part of a Degree; and therefore, to correct this

Error, double the Log. of  $\frac{z}{a}$ , and to the Product

add the Log. of  $\frac{R z}{a}$ , and we shall have the Log. of



of  $\frac{R z^3}{a^3}$ , and the Number answering to it, is

0,04552, whose Half 0,02276 is equal to  $\frac{R z^3}{2 a^3}$ :

This being subtracted from the former, there will remain 5,2841 for the Arch NQ; which is not the 10000th Part of a Degree distant from the Truth. 'Tis here to be observ'd, that though the

second Term of the Series be  $-\frac{R a + 2 R c \times z^3}{2 a^4}$

yet the Part of it  $-\frac{R z^3}{2 a^3}$  is sufficient to determine

AQ truly to the 10000th Part of a Degree.

HAVING found the Arch AQ, or the Angle ACQ, we compute the Angle ASQ by the Resolution of the Triangle QCS, whose Sides QC and CS are given, with the Angle contained between them; and then the Logarithm Tangent of the Angle ASQ is to be diminished, by taking from it the Logarithm of the *Ratio* of the greater Axis to the less: And then there will remain the logarithmick Tangent of the Angle ASP, which is the true or coequated Anomaly.





## LECTURE XXIV.

*Sir ISAAC NEWTON's Solution  
of Kepler's Problem ; and Ward's  
Elliptick Hypothesis explained.*

OUR Method of Solution, explained in the preceding *Lecture*, and that of Sir ISAAC NEWTON's delivered by him in his *Principles*, pag. 101, are built upon the same Foundation ; which is, that the right Line SF is equal in Length to the Arch QN : But the *Newtonian* Method is not unlike to that used by the *Analysts*, when they extract the Roots of affected Equations : And it is so much more to be valued, that it not only gives easily the Planets Places, whose Orbits are nearly circular, but almost with the same Ease it may be used to determine the Comets Places, who have very eccentric Orbits. And this may likewise be performed by our Method, if instead of the Arch AN, we take another Arch A, more nearly equal to AQ, whose Sine is  $e$  ; and instead of making  $z = ge$ , suppose  $z = ge + A - AN$ . And finding the Sine of the Arch  $A + y$  we shall come to an Equation of the same Form with the former, where  $z$  and  $y$  are much less, and consequently the Series will converge much faster.

I will here explain the *Newtonian* Method, since it is of great Use and Expedition, for the Sake of those who are willing to calculate Tables upon Principles grounded on the true Laws of Motion, and not upon absurd Hypotheses.

WE



B  
M

Q  
FL

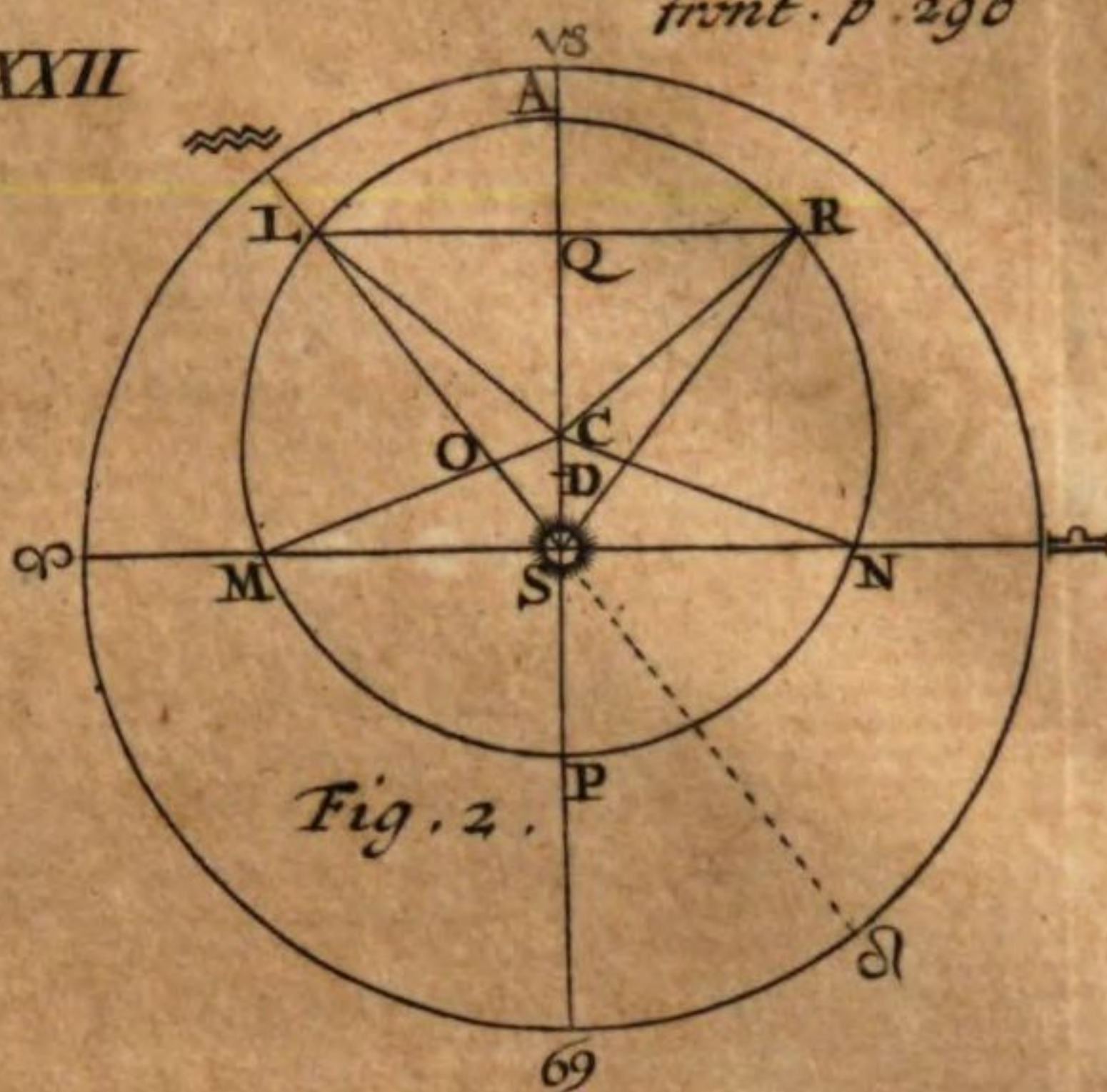
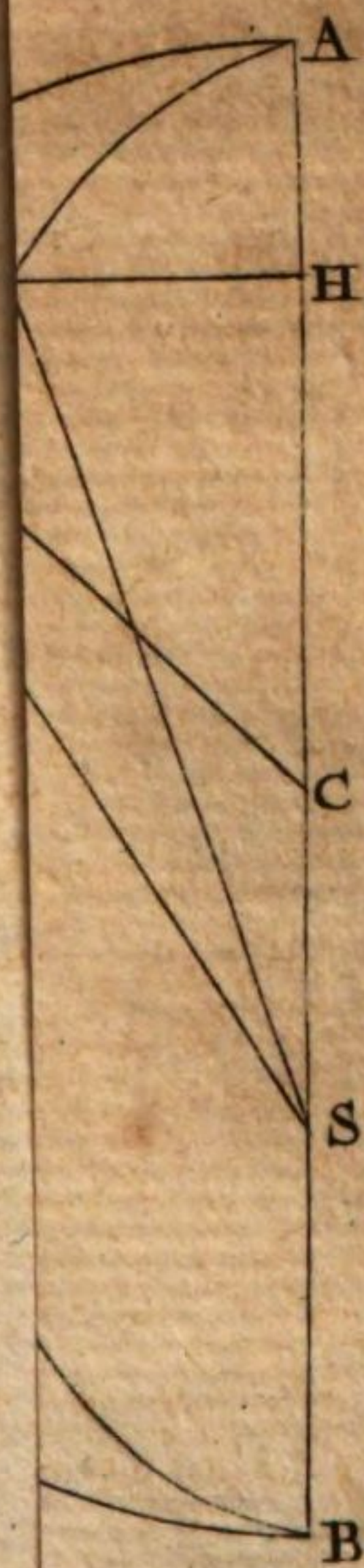
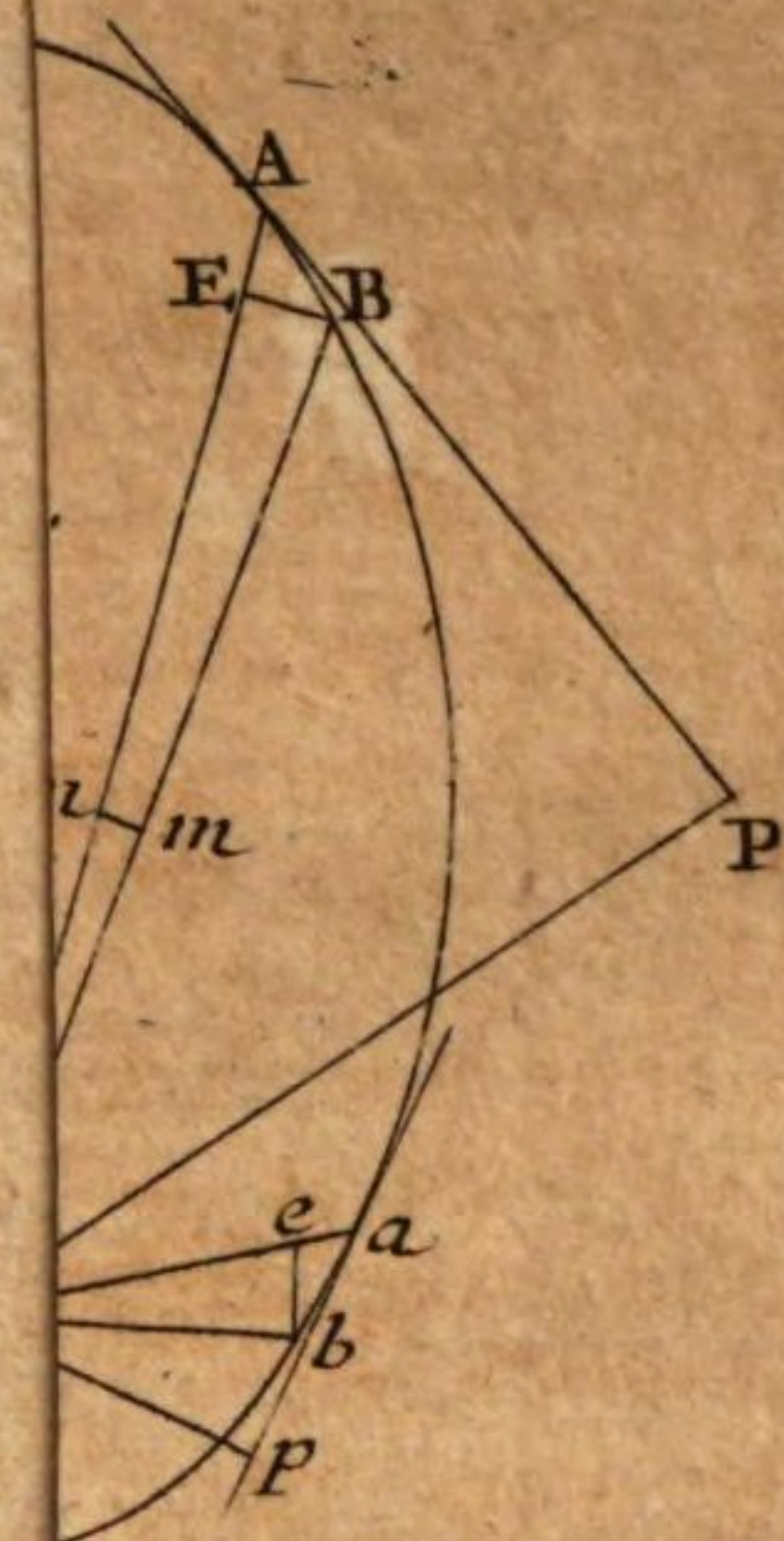


Fig. 2.

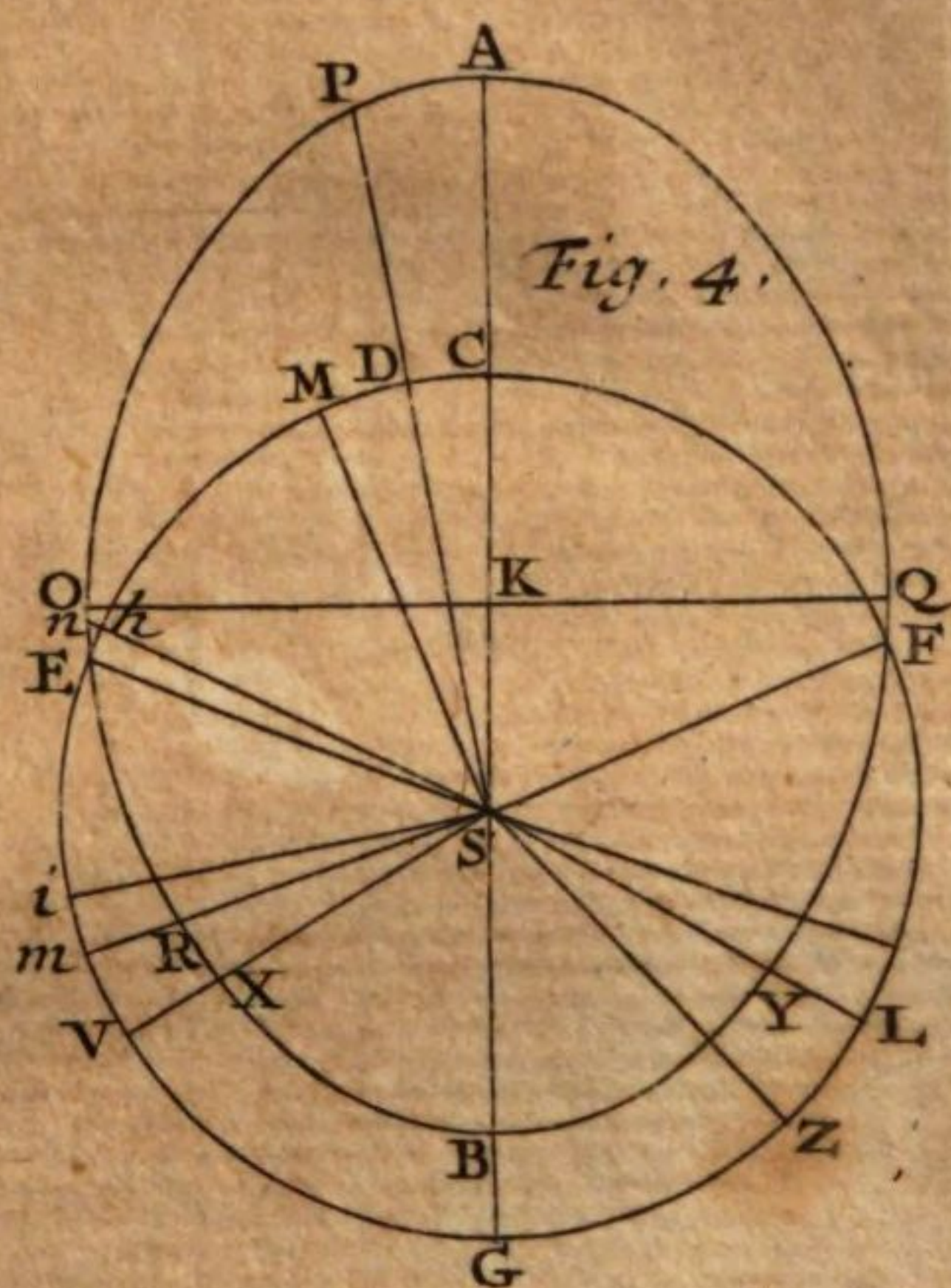


Fig. 4.

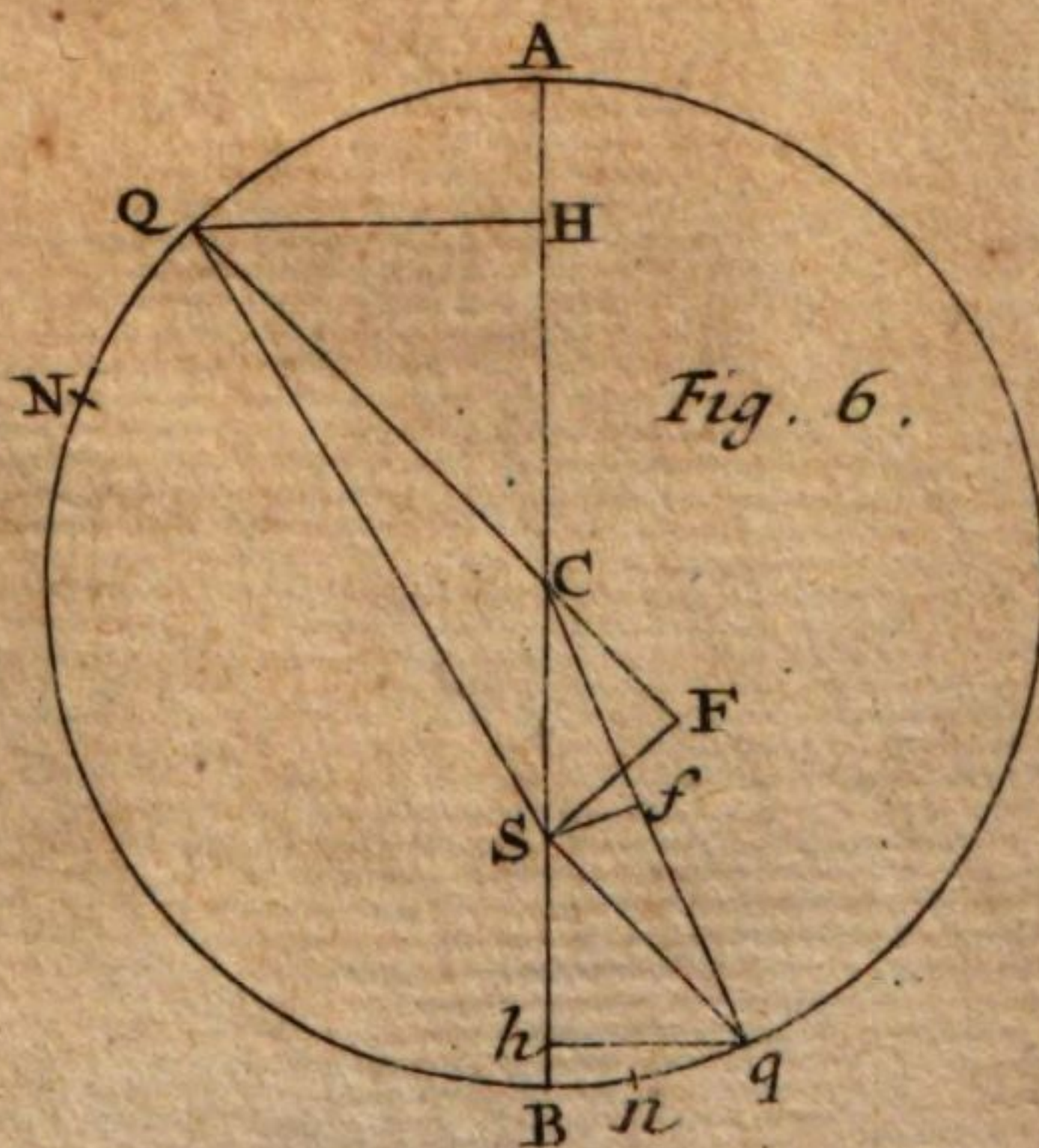


Fig. 6.







WE have already shewed that if the Arch, *AQ* be the Anomaly of the Eccentric, that, together with the right Line *SF* let fall from *S* upon the Radius *CQ* perpendicularly, will be proportional to the Time when the Planet descends from the *Aphelion* to the *Perihelion*; and the Difference between the Arch *BQ* and *SF* proportional to the Time, when it ascends from the *Perihelion* to the *Aphelion*: And therefore, if we take the Arch *AN* or *BN* proportional to the Time, the Arch *QN* will be equal to *SF*. Therefore, to find in Degrees and decimal Parts the Measure of an Arch in the Periphery which is equal to *SF*: Say, as *CQ* is to *CS*, so is 57,29578 Degrees, which is equal to the Radius, to a Fourth: This Number will express the Bigness of an Arch in the Periphery *AQB* which is equal to *CS*: The Log. of this Arch call *B*. And because *SC* is to *SF*, as the Radius is to the Sine of the Angle *ACQ*; say, as the Radius is to this Sine, so is the Arch whose Log. is *B*, to another, which call *D*; then this Arch *D*, will be equal to *SF*. And therefore, if at the given Time, the Arch *AN* and the Area *ASQ* are proportional each to the Time, and I take *NP* equal to *D*, the Point *P* will fall on *Q*: But if the Area *ASQ* be not exactly proportional to the Time, the Point *P* will either fall above or below *Q*, according as the Area *ASQ* is bigger or less than the Truth. Let the true Area be *ASq*, and upon *Cq* let fall the Perpendicular *SE*; which, by what we have already shewed, is equal to *Nq*: And therefore *SE* — *SF* or *SF* — *SE*, that is, nearly the Line *LE*, is equal to  $qP = QP - Qq$  or  $Qq - Qp$ . Now, if the Angle *QCq* be small, we have  $CE : Cq :: LE : Qq :: QP - Qq : Qq$ . And therefore  $CE + Cq : Cq :: QP : Qq$ . After the same way, when *Bq* is less than a Quadrant,  $Cq - CE : Cq :: QP : Qq$ . When the Planet is near the *Aphelion* or *Perihelion*, *CE* becomes nearly equal to *CS*; and  $CQ + CE$  is almost the same with *AS*: And therefore  $QP : Qq :: AS : AC$ , when

the

Lecture  
XXIV.Tab. XXIII  
Fig. 1.



Lecture the Arch  $Aq$  is less than a Quadrant, but when  
 XXIV.  $Bq$  is less than a Quadrant, then as  $SB : CB ::$   
 $QP : Qq$ . Say, as  $CS : CQ :: R$  the Radius to

a Line  $L$ , and then  $CQ = \frac{CS \times L}{R}$ . Also the

Radius is to the Co-sine of  $ACQ$  as  $SC : CF$   
 or  $CE$ , which are nearly equal: Wherefore

$CE = \frac{SC \times \text{Co-sine } AQ}{R}$ , whence we have the

Analogy  $QP : Qq :: \frac{SC \times L + SC \times \text{Co-sine } AQ}{R}$ .

$\frac{CS \times L}{R} :: L + \text{Co-sine } AQ : L$ ; when  $AQ$  is

less than a Quadrant: But if it be greater than a  
 Quadrant,  $QP$  will be to  $Qq :: L - \text{Co-sine}$   
 $AQ, L$ . And in this Manner, if there be an  
 Arch taken as  $Aq$ , which is either a little less or  
 bigger than the Truth, we shall find the Arch  $AQ$ ,  
 which is to be added or subtracted; so that the  
 Area  $ASQ$  may be nearly proportional to the  
 Time. And if instead of  $AQ$  we take another  
 Arch  $AQ$ , and argue as in the former Arch, we  
 shall have a new  $Aq$ , nearer to the Truth: And  
 by this Means, we shall constantly approach to the  
 true Arch, so that the Difference may be less than  
 any given Quantity.

THERE is no need of explaining this Method  
 any farther, we will only illustrate it with Ex-  
 amples, in the Motions of the Planet *Mars*. In  
*Mars's* Orbit the Logarithm  $B$ , is 0,7244446; and  
 the Longitude  $L$ , is 1080631 of such Parts as the  
 Radius is 100000.

LET us find the Angle  $ACQ$ , when the mean  
 Anomaly or Arch proportional to the Time is  
 only one Degree: Because  $CS$  is almost the tenth  
 Part of  $CA$ . I suppose  $AQ$  to be 0,9 Deg. that  
 is a tenth Part less than the mean Anomaly. Add  
 the Log. Sine of 0,9 to the Log.  $B$ , and the  
 Sum is 8,9205466 = to the Log. of the Number  
 0,083281; this Number expresses the Bigness of  
 an



an Arch equal to  $SF = NP$ : And if the Arch  $AQ$  had been rightly assum'd,  $AN - NP$  had been equal to  $AQ$ , and  $QP = 0$ . But in the present Case,  $QP$  is equal  $0,01671$ ; from which, if I take away its tenth Part, because  $AS$  is greater than  $AC$ , by about a tenth Part, we shall have  $Qq = 0,01504$ , which being added to  $AQ$ , gives  $Aq = 0,91504$ .

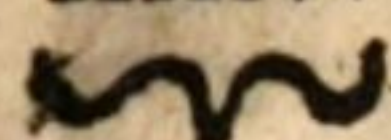
2dly, LET the Arch  $AN$ , or the mean Anomaly be 2 Degrees; I suppose the Arch  $AQ$  to be  $1,83$ , almost double of the former; and adding to its Log. Sine the Log. B, the Sum is  $9,2286992$ , the Log. of the Number  $0,16931$ . And then  $QP = 0,00069$ ; from which, subtracting a tenth Part,  $Qq$  is nearly  $= 0,00063$ , and  $Aq = 1,83063$ , which is not the 10000th Part of a Degree different from the Truth.

3dly, SUPPOSE the Arch proportional to the Time, to be three Degrees, I take  $AQ$  to be  $2,745 = 1,83 + 0,915$ ; and to its Log. Sine, adding the Log. B, we have the Log. of the Number  $0,25392 = NP$ , and  $AN - NP = 2,74638$ , therefore  $Qq = 0,001$  nearly, and  $Aq = 2,746$ : So that by one Addition of two Logarithms, we have the Arch  $Aq$ , true to the thousandth Part of a Degree.

4thly, Now if we should not proceed by single Degrees, but were to find the Angle  $ACQ$ , when the mean Anomaly is much larger; for Example,  $45^\circ$ : I make my Supposition, that the Arch  $AQ$ , is 40 Degrees, and to its Log. Sine, add the Log. B; the Sum is  $0,5320121$ , equal to the Log. of the Number  $3,4081$ , which Number subtracted from 45, leaves  $AN - NP = 41,5919$ , which exceeds the Arch  $AQ$  by  $1,5919$ . And therefore, if we take as  $L + \text{Co-sine } AQ$  to  $L$ , so  $1,5919$  to to a Fourth, we shall have the Arch  $Qq = 1,4865$ . And therefore  $Aq = 41,4865$ , which does not differ much above the thousandth Part of a Degree from the Truth. But without this Proportion we might have found  $Aq$ , by taking an Arch which is somewhat less than  $AN - NP$ , but nearly equal to it. Suppose we had made  $AQ = 41,5$ , and adding



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XXIV.



ding its Log. Sine to the Log. B we shall have another Arch  $NP = 3,5132$ , which subtracted from  $AN$  gives  $41,4868$ , for a new  $Aq$ . And this Arch is easier found, than by the former Proportion; and besides, comes nearer to the Truth, than the last  $Aq$  was.

5thly, AFTER having found  $Aq$ , or the Anomaly of the Eccentric, that answers to the mean Anomaly of 45 Degrees; if we should again proceed by single Degrees, by only one Addition of two Logarithms, we may find the Anomaly of the Eccentric, to all the following Degrees of the Semicircle, viz. when the mean Anomaly is 46 Degrees, I make  $AQ$  to be 42,4, and adding its Log. Sine, to the Log. B, I find  $AN - NP = 42,4249$ ; to which, if I make the new  $AQ$  equal, I shall have an  $Aq$ , which is not 1000th Part of a Degree distant from the true Anomaly of the Eccentric. So likewise, when the mean Anomaly is 47 Degrees, I take  $AQ = 43,36$  to the former  $Aq$  + the Increment that accrues to it, by adding a Degree: And adding the Log. B, to the Log. Sine of 43,36, the Sum is the Log. of the Number 3,6402, which subtracted from  $AN$ , leaves  $AN - NP = 43,3598$ , equal to a new  $Aq$ : And this Arch is about the 10000th Part of a Degree, different from the true Anomaly of the Eccentric.

6thly, IF again, passing over the intermediate Degrees, I would find the Arch  $Aq$ , when the mean Anomaly is 100 Degrees; I make  $AQ$  equal 96 Degrees, and adding its Log. Sine to the constant Log. B, the Sum is the Log. of the Number 5,273, and  $AN - NP = 94,727$ . Therefore I put again  $AQ = 94,72$ , and adding together its Log. Sine, and the Log. B, I have the Log. of the Number 5,285, which subtracted from  $AN$ , leaves  $Aq = 94,715$ . In like manner, when the mean Anomaly is 101 Degrees, I make  $AQ = 95,71$ ; and I find  $NP$ , to be 5,2756, which subtracted from 101, leaves  $Aq = 95,7244$ . And here again, if we proceed by Degrees, we shall have



have the eccentric Anomaly, constantly by the Lecture Addition of two Logarithms, one of which being XXIV. constantly the same, may be set once down in a Piece of Paper by itself, and the Labour sav'd of frequently transcribing it.

LET us now pass to another Sort of Orbit, whose Eccentricity bears a great Proportion to its mean Distance. For Example, Let us suppose the *Aphelion* Distance, to be to the *Perihelion* Distance, as 70 is to 1; and such is nearly the Orbit of that Comet, which Dr. *Halley* first found to complete its Period in  $75\frac{1}{2}$  Years. Here A C or C Q, the mean Distance, is 35,5, and C S is 34,5, of such Parts as S B is 1. And the constant Log. B is 1,7457133. We must find the Arch B q, when Tab. XXII., the mean Anomaly computed from the *Perihelion*, Fig. 6, is  $1\frac{1}{100}$  of a Degree. I suppose B Q to be 0,35: To its Log. Sine, add the Log. of B, and the Sum is the Log. of the Number 0,34013, which added to the Arch A N, makes ,35013. If this Arch had been only 35, B Q had been rightly taken; but the Difference is 0,00013. And therefore because C B is to S B, as 35,5 to 1; multiply the Difference ,00013 by 35,5, and we shall have Q q = ,004615, and the Arch B q = 0,354615; and the Error less than ,0003 of a Degree. Again, let the mean Motion be ,02, I put B Q = 0,71, and adding its Log. Sine and B together, I have the Log. of the Number 0,68998, and B N + N P = ,70998: The Difference is 0,00002; which multiply by 35,5, and the Product subtracted from B Q, leaves B q = 0,7092; and the Error is not greater than the  $1\frac{1}{10000}$  Part of a Degree. If the mean Anomaly be 0,03, I make B Q = 1,06, and adding its Log. Sine to B, I have the Log. of the Number 1,03008, to which add the Arch B N; the Sum is 1,060088, which is greater than B Q: Wherefore, if the Difference ,00008, be multiplied by 35,5, and the Product added to B Q, we shall have B q = 1,06284. In the same manner, when the mean Anomaly is ,04, I suppose B Q 1,4, and I find P N = 1,3604, to which adding



Lecture XXIV. adding ,04, the Sum is 1,4004, which exceeds 1,4 by ,0004; multiply this Difference by 35,5, and the Product will be ,0142 =  $Qq$ , and therefore  $Bq = 1,4142$ . In all these Examples, the Errors are very small, seldom exceeding the 1000th Part of a Degree.

LET us now find the Anomaly of the Eccentric, when the mean Anomaly is one Degree. Here I make  $BQ = 20$  Degrees, and adding its Log. Sine to B, I have the Log. of the Number 19,045, to which adding 1 the Sum is 20,045, and is greater than 20 by ,045. And because in this Example,  $L - \text{Co-sine } BQ$  is to L, as 1 is to 11,5 nearly: I multiply the Difference ,045 by 11,5, and the Product 0,5175, added to  $BQ$ , makes 20,5175. Therefore 2dly, I make  $BQ = 20,51$ , and  $NP$  will be 19,5092; to which, adding  $BN$ , the Sum is 20,5092. And therefore, if the Difference ,0008, be multiplied by 11,5, and the Product ,0092, subtracted from  $BQ$ , there will remain  $Bq = 20,5008$ .

Lastly, LET the mean Anomaly be 2 Degrees; I put  $BQ = 30$  Degrees, and then I find  $NP = 27,84$ ; to which adding 2, and the Sum is 29,84, which is less than 30 Degrees: Multiply the Difference ,16 by 6,3, (for  $L - \text{Co-sine } BQ$  is to L, as 6,3 to 1,) and we have 1,008 =  $Qq$ : And therefore, this Arch subtracted from  $BQ$ , gives  $Bq = 28,982$ . Therefore, to correct the Error, I put again  $BQ = 29$  Degrees; and by a like Process, I find  $Bq = 28,9672$ . Having found the Angle  $ACQ$ , the Angle  $ASQ$  is easily found. For in the Triangle  $QCS$ , we have the Sides  $QC$ ,  $CS$ , and the Angle  $QCS$ : Therefore we shall find the Angle  $ASQ$ , and the Side  $SQ$ ; then say, as the greater Axis of the Ellipse is to its less, so the Tangent of the Angle  $ASQ$ , is to the Tangent of  $ASP$ , which will thereby be found; and it is the coequated or true Anomaly. Again, say, as the Secant of the Angle  $ASQ$  is to the Secant of  $ASP$ , so is  $SQ$  to  $SP$ , the Distance of the Planet from the Sun. Or perhaps  
these

Tab. XXII.  
Fig. 5, 6.



these Things may be easier computed in this Manner. Having the Arch  $AQ$ , we have its Sine  $QH$ , and its Co-sine  $HC$ : But we have  $SC$ , in such Parts as the Radius, or  $CQ$  is 100000; therefore we have  $HS$ . Say, as the greater Axis of the Ellipse is to its less, so is  $QH$  to  $PH$ , which will therefore be given. In the rectangle Triangle  $PHS$ , we have also the Sides  $PH$  and  $HS$ , wherefore we can find  $PSH$  the true Anomaly, and  $PS$  the Distance of the Planet from the Sun.

BECAUSE in the *Aphelions* and *Perihelions*, the Points  $Q$  and  $N$ , or the mean and true Place of a Planet coincide; and in the first Semicircle of Anomaly, the mean Place is before the true Place, in the second, the mean Place is behind the true; if we have determined the Position of the *Apsides* of the *Earth's* Orbit, we shall know the Time when the true and mean Place coincide. For when the Sun is observed in that Point of the Ecliptick where the *Perihelion* is, then the Earth is in the *Aphelion*. And having this Moment of Time, by *Astronomical* Tables, we shall have the mean Anomaly for any other Time, as likewise the Arch  $AN$ . For these Arches are computed according to the Proportion of the Times, and are placed orderly in the Tables. Now having for any Point of Time the Arch  $AN$ , we have shewed, how from thence we may compute the true Anomaly, and the Place of the Earth in the Ecliptick, to which the Place of the Sun is always opposite.

BESIDES the Theory of *Kepler*, according to which the Planets do really regulate their Motions, there is another elliptick Hypothesis, which has been chiefly improved by two most celebrated Astronomers, *Ismael Bullialdus*, and Dr. *Seth Ward*, formerly Professor in this Chair, and afterwards Bishop of *Salisbury*, by whose Pains *Astronomy* has been much advanced. And since this Hypothesis does not want Elegance, and a Neatness in Geometry; and besides, it admits of an Easiness in computing, we will here briefly explain



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XXIV.



plain it. In this Hypothesis with *Kepler*, it is supposed, that the Planets Orbits are *Ellipses*, and that they have all one common Focus, in which the Sun resides. Moreover, they suppose, that each Planet does move in the Periphery of its Orbit, in such a Manner, that drawing Rays or Lines to the other Focus, they describe Angles proportional to the Times. These Things being supposed, Dr. *Ward* shews an elegant Method of finding the true Anomaly from the Mean, having determined the Species of the Planet's Orbit ; And it is as followeth.

Tab. XXIII  
Fig. 2.

LET *APB* be the Ellipse which the Planet describes, *AP* the Line of the Apfides, *S* the Focus, in which the Sun is placed, *F* the other, or the upper Focus, which is the Center of equal Motion. Let the Angle *AF L* be proportional to the Time, or be the mean Anomaly, then *L* will be the Place of the Planet in its Orbit, and the Angle *AS L*, the co-equated or true Anomaly. Produce *FL* to *E*, so that *FE* may be equal to *AP* the greater Axis of the Ellipse ; and therefore, since by the Nature of the Ellipse, *FL* and *LS* are equal to the same *AP*, then *LE* must be equal to *LS*, and the Triangle *LSE* will be an Isosceles Triangle ; and therefore the Angles *E* and *ES L* are equal ; and the exterior Angle *FLS*, being the Sum of both, will be the double of each, or double of the Angle *LES*. Therefore, in the Triangle *EFS*, having *FE* and *FS*, and the Angle *EFS*, which is the Complement of *LFA* to two Rights, we can find the Angle *E*, whose double, is equal to the Angle *FLS*, which therefore will be known : But the Angle *AF L*, is equal to the two Angles *FS L* and *FLS*, and therefore the Angle *FLS*, is the *Prosthaphæresis* or the Equation, which is to be subtracted from the mean Anomaly, or added to it, to have the true Anomaly.

IN resolving the Triangle *EFS*, having *EF* and *FS*, the Analogy is  $\frac{1}{2} EF + \frac{1}{2} FS : \frac{1}{2} EF - \frac{1}{2} FS$  ; that is, as *AS* to *SP* :: Tang.  $\frac{1}{2} AFE$  : Tangent of  $\frac{1}{2}$  Difference of the Angles *E* and *FSE* ; but  
be-



because the Angle  $E$  is  $= LSE$ ,  $FSL$  is the Difference of the Angles  $E$  and  $FSE$ ; wherefore the Angle, found by the Analogy, being doubled, gives the Angle  $FSL$ , which is the true Anomaly. Now the Practice here is extremely easy; for because  $AS$  and  $SP$  are constant Quantities, the Difference of their Logarithms is a constant Quantity; wherefore a given Number is to be added to Log. Tangent of half the mean Anomaly, and then we shall have the Tangent of half the true Anomaly. Moreover, in the Triangle  $LFS$ , having all the Angles, and the Side  $SF$ , we can find  $SL$  the Distance of the Planet from the Sun.

THIS Hypothesis of Dr. *Ward's* is a very useful Approximation, and serves to shorten the Calculation, and make it easy: But yet it is still only an Approximation, and does not come up to the Truth: We will here shew the Reason of it. Let  $APB$  be the Orbit of the Planet,  $AQB$  the Circle circumscribed; the Arch  $AQ$  the Anomaly of the Eccentric, and  $AN$  the mean Anomaly. From the Center  $C$  draw  $NC$ , and  $QG$  parallel to it; the Angle  $QGA$  is equal to  $NCA$ , or the mean Anomaly; and  $CG$  will be nearly equal to  $CS$ , but a little less than it. For from the *Focus*  $S$ , on  $QC$  let fall the Perpendicular  $SF$ , which we shewed before to be equal to the Arch  $QN$ : But because the Arch  $QN$  is small, its Sine will be almost equal to the Arch; and therefore  $GO$ , a Perpendicular on  $NC$ , will be nearly equal to  $SF$ , but somewhat less. But the Triangles  $GOC$ , and  $SFC$ , are nearly equiangular, (for  $NCQ$ , the Difference of the Angles  $GCO$ , and  $SCF$ , is very small) and therefore, because  $OG$  is almost equal to  $SF$ , but a little less than it;  $CG$  will be almost equal to  $CS$ , but somewhat less. The other *Focus* of the Ellipse then, must be a little above the Point  $G$ , but very near it; and if we draw from the Planet's Place the Line  $PL$ , parallel to  $QG$ , the Point  $L$  will be likewise above the Point  $G$ , but yet not far distant from it; and therefore, the Point  $L$ , and the other *Focus* of the Ellipse, do nearly coincide. But the Angle  $PLA$



Lecture XXIV. is equal to  $NCA$ , the mean *Anomalia*; and the Point  $L$ , nearly coinciding with the other *Focus*, the Line drawn from  $P$  to the other *Focus* will make an Angle with the Axis, nearly equal to the Angle  $PLA$ , or  $NCA$ , that is, to the mean Anomaly. And therefore the Angles, at the superior *Focus*, are nearly proportional to the Times.

WHERE the Angles  $NCA$  and  $QCA$ , or  $SCF$ , differ but little from one another, that is, where the Angle  $NCQ$ , and the Eccentricity are but small, the Points  $G$  and  $L$ , are nearly coincident with the superior *Focus*. And therefore this Theory is accurate enough to answer to the Motion of the Earth, whose Orbit is nearly circular: But in the other Planets, and particularly *Mars* and *Mercury*, it does not do so well. And therefore, *Bullialdus*, from four Places of *Mars*, observed by *Tycho*, in the first and third Quadrant of Anomaly, found, that *Mars* was further advanced in his Orbit, than he ought to be by this Theory. But in the second and fourth Quadrants, *Mars's* true Anomaly was found to be less than it should be, according to this Hypothesis; and therefore *Bullialdus* gave it the following Correction. Upon the Diameter  $AP$ , which is the greater Axis of the Ellipsis, describe the Circle  $ADP$ . Let  $AF L$  be the mean Anomaly; through  $L$  draw the Line  $QLG$  perpendicular to the Axis, meeting with the Circle in  $Q$ . Join  $FQ$ , which cuts the Ellipse in  $\gamma$ , and  $\gamma$  will be the Place of the Planet in its Orbit, answering to the mean Anomaly  $AF L$ . Now the Angle  $AFQ$ , answering to the mean Anomaly  $AF L$ , is easily found by taking an Angle whose Tangent is to the Tangent of  $AF L$ , as the greater Axis of the Ellipse is to the lesser. And having the Angle  $AFQ$ , or  $AF\gamma$ , the Angle  $AS\gamma$  is found in the same Manner as before the Angle  $ASL$  was found.

Plate XXIII.  
Fig. 2.

THE Calculations we have here explained, suppose that the Species, or Forms of the Orbits are given, as likewise their Positions. We shall afterwards shew a Way by which the Orbits of the other Planets are determined: But the Form and Position of



Of the Earth's Orbit is to be found by the following Methods. First, observe the apparent Diameter of the Sun, as likewise his Motion; for when the Earth is in its *Aphelion*, the Sun's Diameter is the least of all, and his Motion slowest; the Earth being there at the greatest Distance from the Sun. In the *Perihelion*, it coming nearest the Sun, we shall observe his Diameter to appear biggest. Let any right Line *SP*, represent the *Perihelion* Distance of the Sun: Say, as the apparent Diameter of the Sun in the *Aphelion* is to its apparent Diameter in the *Perihelion*, so is *SP* to a Fourth. In *SP* produced, take *SD* equal to this Fourth, and it will be the *Aphelion* Distance; bisect *PD* in *C*, and *CS* will be the Eccentricity, and *C* the Center. Describe an Ellipse, whose *Focus* is *S*, and greatest Axis *PD*; that Ellipse will be of the same Form with the Earth's Orbit; and the Points of the Ecliptick, where the Sun's Diameter appears the biggest and the least, shew the Position of the *Apsides*, or the *Aphelion* and *Perihelion*. But because the Diameter of the Sun, in the *Aphelion* and *Perihelion*, is scarcely seen to alter its Bigness for some Days, it will be very difficult to determine the Position of the *Apsides*, by Observations made on the apparent Diameter of the Sun only; and therefore, it will be better to find out the *Aphelion*, and *Perihelion* Distances and Positions, by observing the Sun's Motion: For the angular Velocity of the Earth, and the apparent Motion of the Sun, which is equal to it, is always reciprocally as the Square of the Distance, as we have above demonstrated.

THEREFORE, to determine the Species of the Ellipse, in which the Earth moves, we must observe the apparent Velocities of the Sun when it is greatest and least. Call the least *A*, and the greatest *B*; and let any right Line *SP*, represent the *Perihelion* Distance: Say, as *A* is to *B*, so is *SP* to another Line *C*. Produce *SP* to *D*, so that *SD* may be a mean Proportional between *SP* and *C*; this Line *SD* will represent the *Aphelion* Distance: And therefore, if the Ellipsis be described, whose *Focus* is *S*, and its



Lecture greater Axis  $PD$ , that Ellipse will be of the same  
 XXIV. Form with the Earth's Orbit. For because  $SP$ ,  $SD$ ,  
 and  $C$ , are continually proportional,  $PS$  square,  
 will be to  $DS$  square, as  $SP$  is to  $C$ , or as  $A$  to  $B$ ,  
 that is, as the Velocities. Moreover, if the Places  
 of the Ecliptick be diligently marked, where the  
 Velocities are greatest and least, in those Points will  
 the *Apsides* be situated. Lastly, If there be two  
 Places of the Ecliptick observed, where the Sun's  
 apparent Velocities are equal, and the Arch of the  
 Ecliptick between the two Places be bisected, the  
 Point of Bisection, and its opposite, will shew the  
 Places of the *Apsides*. But these Methods require  
 Observations that are very nice and accurate, such  
 as can scarcely be made.

FROM the Theory of Dr. *Ward*, we have a more  
 certain Method of finding the Form of the Orbit, by  
 three Observations of the Sun, and marking the Time  
 between them; which does likewise determine the  
 Position of the *Apsides*. Let  $ABPDC$  be the Or-  
 bit of the Earth,  $S$  the *Focus* in which the Sun is  
 placed,  $F$  the other *Focus*: The *Apsides*  $A$  and  $P$ .  
 Let  $B$ ,  $C$ , and  $D$ , be three Places of the Earth in  
 the Ecliptick, which are found by observing three  
 Places of the Sun, to which they are opposite. At  
 the Center  $F$ , and Distance  $FM$ , equal to the greatest  
 Axis of the Ellipse, describe the Circle  $MHEL$ ;  
 and let the Lines  $FB$ ,  $FC$ ,  $FD$  produced, meet  
 with the Circle in the Points  $G$ ,  $H$ ,  $E$ . Draw like-  
 wise from the *Focus*  $S$ , the Lines  $SB$ ,  $SC$ ,  $SD$ , as  
 also  $SG$ ,  $SH$ , and  $SE$ . We have the Angles  $BSC$ ,  
 $BSD$ , and  $CSD$ , for they are measured by the  
 Arches of the Ecliptick, intercepted between the  
 Points observed. But, according to this Theory, the  
 Earth moves in the Perimeter of an Ellipse in such  
 a Manner, that it describes Angles about the *Focus*  $F$ ,  
 that are proportional to the Times: And therefore  
 we shall have the Angles  $BFC$ ,  $BFD$ , and  $CFD$ ,  
 taking each of them such, that they may have the  
 same Proportion to four right Angles, as the Times  
 between the Observations have to the whole periodi-  
 cal

Plate XXIII.  
 Fig. 5.



cal Time. Moreover, twice the Angle  $FGS$ , that is, the Angle  $FBS$ , is the Difference of the Angles  $AFB$ , and  $ASB$ : This we shewed before. And the Double of the Angle  $FHS$  is the Difference of the Angles  $AFC$ , and  $ASC$ ; the Difference of the Angles  $BFC$ , and  $BSC$ , will therefore be equal to  $2FGS + 2FHS$ . But because we know the Angles  $BFC$ , and  $BSC$ , we know likewise their Difference; therefore, we have the Sum of the Angles  $FGS$ , and  $FHS$ . But the Angle  $FGS$  is the Difference of the Angles  $BFA$ , and  $GSA$ ; and the Angle  $FHS$ , is the Difference of the Angles  $HFA$ , and  $HSA$ : Whence both the Angles  $FGS$ , and  $FHS$ , will be equal to the Difference of the Angles  $BFC$ , and  $GSH$ . But we have the Angle  $BFC$ , and the Sum of the Angles  $FGS$ , and  $FHS$ ; and therefore we have the Angle  $GSH$ . In the same Manner we can find the Angle  $GSE$ . Also, in the same Manner, the Angle  $FES$  doubled, is the Difference of the Angles  $DFA$ , and  $DSA$ ; also the Double of the Angle  $FHS$  is the Difference of the Angles  $CFA$ , and  $CSA$ . And therefore, twice the Angle  $FES$  — twice the Angle  $FHS$ , will be equal to the Difference of the Angles  $CFD$ , and  $CSD$ ; but we have the Angles  $CFD$ , and  $CSD$ : And therefore, we have half their Difference, that is,  $FES - FHS$ . But the Angle  $FES - FHS$ , is the Difference of the Angles  $CFD$ , and  $HSE$ ; and we have the Angle  $CFD$ ; wherefore, we have the Angle  $HSE$ . We have therefore, all the Angles at  $F$ , viz.  $BFC$ ,  $BFD$ ,  $CFD$ , and all the Angles at  $S$ , viz.  $BSC$ ,  $BSD$ ,  $CSD$ ; as also  $GSH$ ,  $GSE$ ,  $HSE$ . These Things being laid down,

Express the Line  $SH$  by any Number, viz. 100000, and produce  $ES$ , till it meets with the Periphery in  $L$ , join  $HL$ ,  $LG$ , and  $HG$ . In the Triangle  $HSL$  we have the Angle  $HSL$ , the Complement of  $HSE$  to two Rights: And the Angle  $HLS$ , equal to half the Angle  $HFE$ , by the 20th *Prop. El. III.* and the Side  $HS$  100000; wherefore, we shall find the Side  $SL$ : Then in the



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Triangle  $SLG$ , we have the Angle  $LSG$ , the Complement of the known Angle  $ESG$  to two Rights; and the Angle  $SLG$ , being half the Angle  $ELG$ , by the 20th *Prop. El.* III. and the Side  $SL$ , therefore we shall find  $SG$ . And again, in the Triangle  $SHG$ , we have the Sides  $SH$  and  $SG$ , and the Angle  $HSG$ ; and consequently we shall find the Side  $HG$ , and the Angle  $SHG$ . In the Isosceles Triangle  $HFG$ , we have the Angle  $HFG$ , and the Base  $HG$ ; wherefore, we shall find the Side  $HF$ , which is equal to the greater Axis of the Ellipse; as also the Angle  $GHF$ , which being subtracted from the known Angle  $GHS$ , leaves the Angle  $FHS$  known. Lastly, In the Triangle  $FHS$ , having  $FH$ , and  $HS$ , and the Angle  $FHS$ , we shall find the Side  $SF$ , and the Angle  $HSF$ ; from which subtracting the Angle  $HSC = FHS$ , there will remain the Angle  $CSF$ , which shews the Position of the *Apfides*.

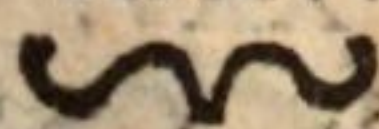
THIS Method does suppose, indeed, that the Angles at the superior *Focus* be always proportional to the Times, which is not true. But in the Orbit of the Earth, whose Eccentricity is small, the Angles that are really described at that *Focus* differ so little from the Angles that are proportional to the Time, that no sensible Error can arise from thence, in determining the Species and Position of the Orbit.

THE most celebrated *Astronomer*, Dr. *Edmund Halley*, from whose Labours *Astronomy* has received great Improvement, hath contrived a Method which depends on no Theory of the Earth's Motion: From which, by Observation alone, the Form and Position of the Orbit are to be determined.

Tab. XXIII.  
Fig. 6.

SUPPOSE the Sun at  $S$ ,  $ABCD$  the Orbit of the Earth,  $P$  the Planet *Mars*, who for this Purpose is to be prefer'd, or chosen before the others. First, Observe the true Time and Place, when *Mars* is in Opposition to the Sun; for then the Sun, the Earth, and *Mars*, are in one right Line; or if it happens (as it often does) that *Mars* has any Latitude, the Sun, the Earth, and *Mars* his Place reduced to the Ecliptick, are in a right Line. Let the Sun, the Earth, and *Mars*, have their Places in the Points  $S$ ,

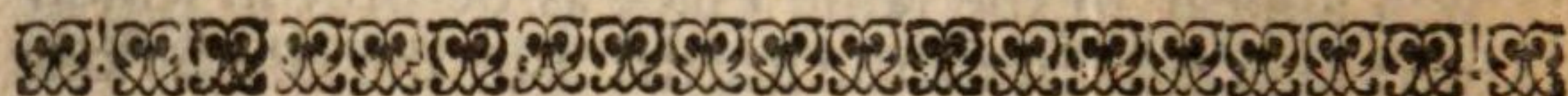




S, A, and P, in the right Line SP. Since *Mars* his Period consists of 687 Days, after that Time, *Mars* will return to the Point P; and seen from the Sun, he will appear in the same Place as before, in which he was seen also from the Earth: But the Earth does not return to A, till after  $730\frac{1}{2}$  Days; and therefore, when *Mars* is in P, it will be in B, and will observe the Sun in the Line SB, and *Mars* in the Line BP. By observing the Places of the Sun and *Mars*, we have all the Angles of the Triangle P B S. And supposing PS to consist of 100000 Parts, we can find the Distance SB, in those Parts, as likewise its Position. After the same Manner, when *Mars* has finished another Period, the Earth will be in C, and we can find the Length of the Line SC, and its Position; and likewise, by the same Method, another Line SD, and its Position, may be obtained. And by this Means we are come to this *Geometrical Problem*: Having three Lines meeting in the *Focus* of an Ellipse, all given in Length and Position, to find the Length of the transverse Axis, its Position and the Distance of the *Foci*: Which Problem, the *Geometers* shew how to construct; and we, in the following Lectures, will likewise give its Solution.







## LECTURE XXV.

*Of the Equation of TIME.*

*Motion, the  
Measure of  
Time,*



ALTHOUGH *Time* be in its own Nature, a real Quantity, as being endowed with the chief Properties of Quantity, Equality, Inequality, and Proportion; yet to measure this Quantity, we must have the Aid and Assistance of Motion, as a Measure to estimate and compare the Quantities of *Times*; and therefore *Time*, when it is considered as measurable, marks out some Motion: For if all Things were at rest, we could by no Means know the Flux, or Quantity of *Time*, and the Duration of all Things would go on without Perception.

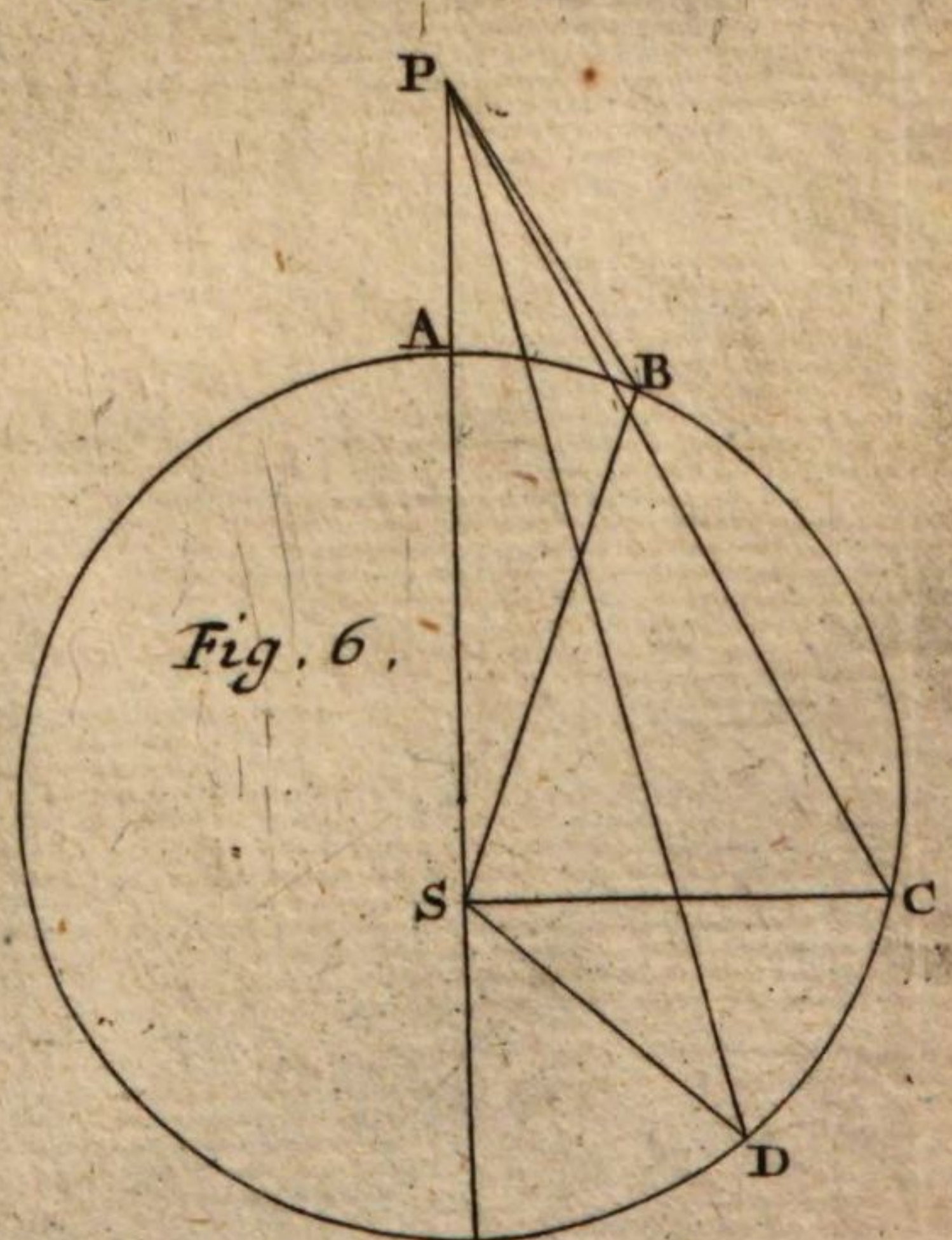
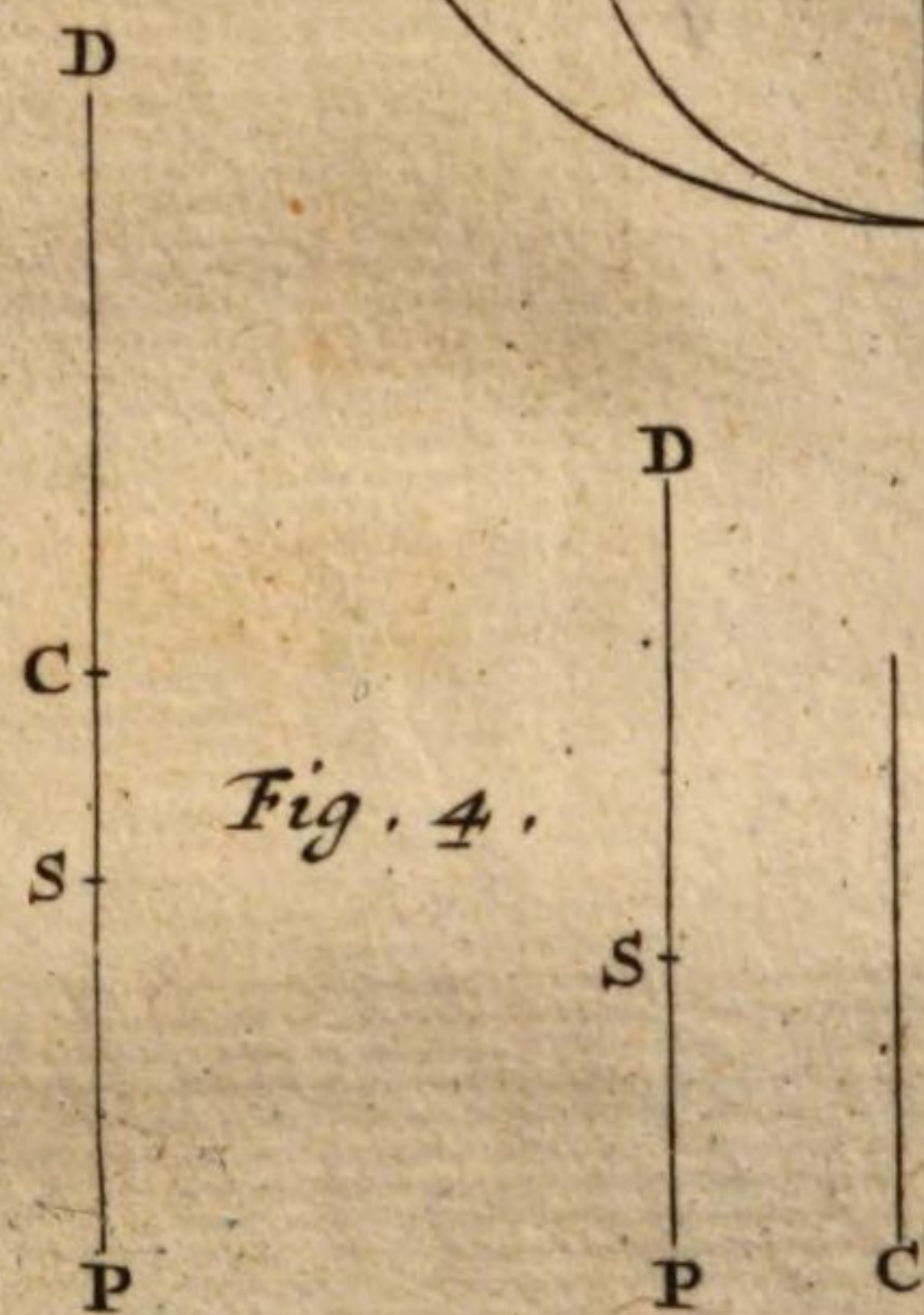
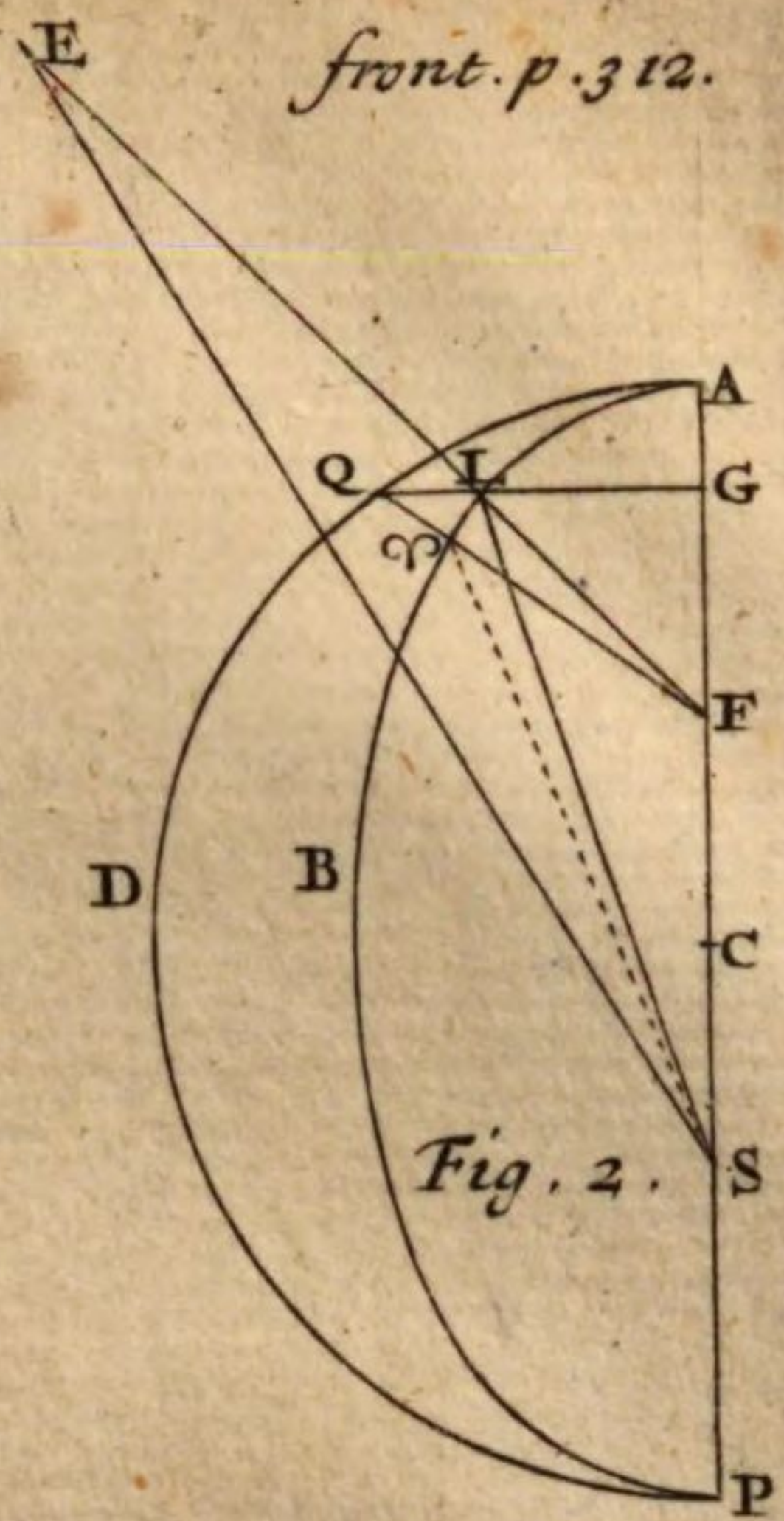
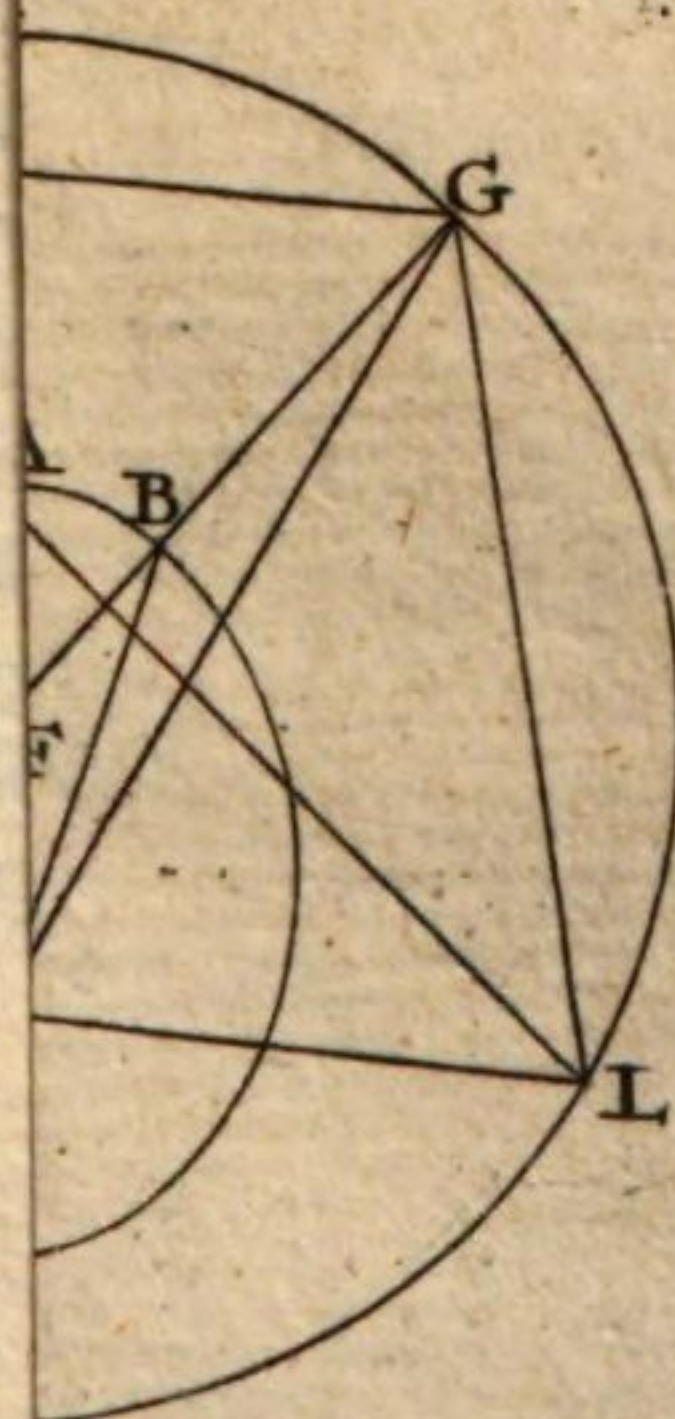
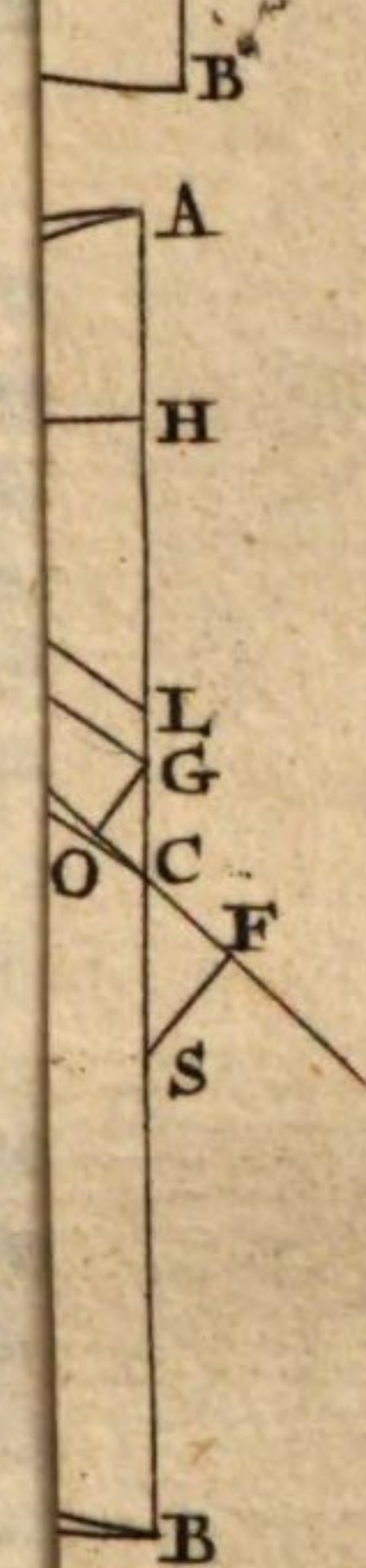
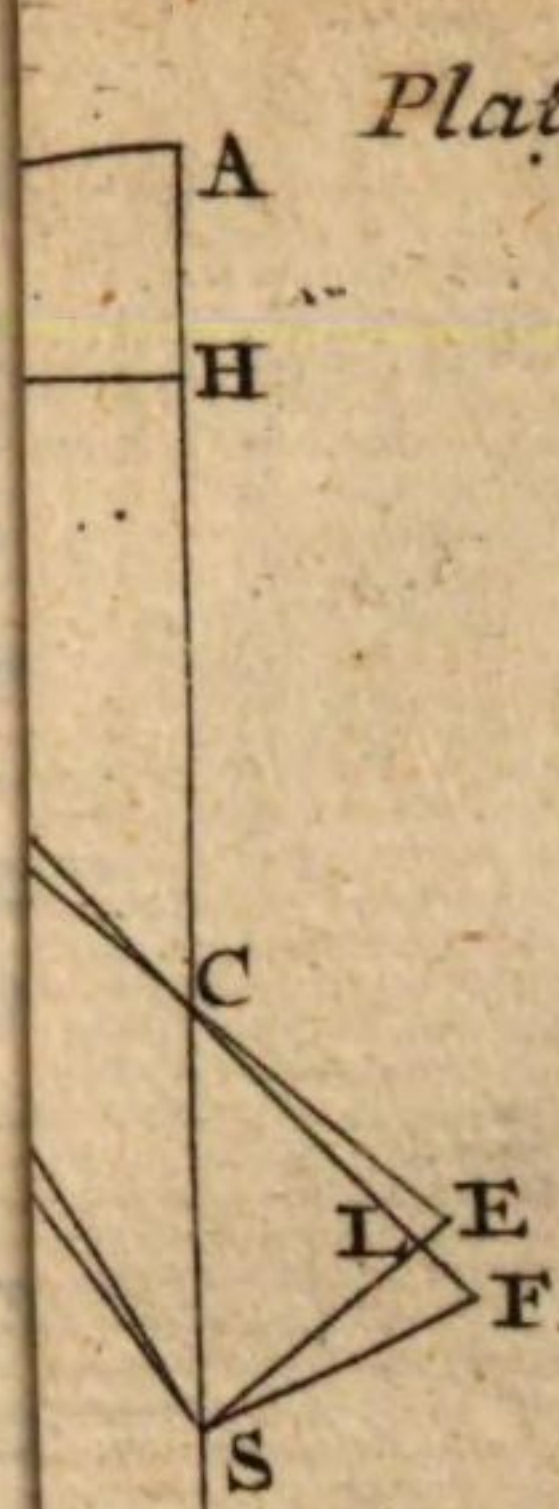
*Uniform  
Motion, the  
proper Mea-  
sure.*

BUT because *Time* constantly flows equally, and in the same Manner, to measure it, we must make Use of such a Motion, as is in itself simple, uniform, and always going on at the same Rate; so that the Body which has this Motion, at least as to its Periods, may always keep the same Force, and yet go thro' equal Spaces in equal *Times*.

*The Motions  
of the Sun  
and Moon,  
the fittest  
Measures.*

FOR common Use, we must take that Motion which is most remarkable, evident to every Body, and plain to common Sense; such is the Motion of the Stars, and chiefly of the Sun and Moon, which not only, by the common Consent of all Mankind, are agreed upon for this Effect, but by the Almighty and wise Creator of the Universe, are established for this Purpose: For in  
the







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the Scriptures we read, that God said, *Let there be Lights in the Firmament of the Heaven, to divide the Day from the Night; and let them be for Signs and for Seasons, and for Days and for Years.* And therefore, by the celestial Motions, and chiefly by that of the Sun, are the Times rightly distinguished and marked out. Who therefore dare say, that the Sun will not tell us Truth! The *Astronomers* are the bold Men who tell us so; for they, by their nice Search into Things, have found, that the Sun's apparent Motion is no ways equal; they observe, that he now and then slackens his Pace, and afterwards quickens it again: And therefore *Equal Time*, which goes on always at the same Rate, cannot truly be measured by the Sun's Motion.

HENCE the *Time* which the Sun's Motion shews, and which is called the *Apparent Time*, is different from that *Time*, which flows uniformly and always at the same Rate, which is called by the *Astronomers* the *True and Equal Time*; according to which all the celestial Motions are to be estimated, regulated and settled. For, upon the Account of the unequal Motion of the Sun, and the Obliquity of the *Ecliptick* to the *Æquator*, we have neither Days nor Hours perfectly equal, as we shall here shew.

THE solar Day is that Space of *Time* which passes while the Plane of the Meridian of any Place, passing thro' the Center of the Sun by the Earth's Revolution turning round its own Axis, returns again to the Sun's Center; or it is the *Time* between one Mid-day, and the next which comes after. Now if the Earth had no other Motion, but that round its Axis, all the Days would be exactly equal to one another, and to the Time of the Revolution round the said Axis. But because, while the Earth is whirling round its Axis, it is also going forward in its proper Motion Eastward; when any Meridian has compleated its Revolution, after having pass'd the Sun's Center, its Plane will not have then passed through the Sun,

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XXV.

The Distinction between the true and equal Time,



Lecture XXV. Sun, as is plain by the Figure. For let the Sun be S, AB a Portion of the Ecliptick; let the Line MD, represent any Meridian, whose Plane produced, passes thro' the Sun when the Earth is in A: Let the Earth proceed in its Orbit, and come to B, while it has compleated a Revolution round its Axis; and then the Meridian MD, will be in the Position  $md$ , parallel to the former MD; and consequently, will not as yet have passed thro' the Sun, nor will the Inhabitants under that Meridian, have had their Mid-day. But the Meridian  $dm$ , with its angular Motion, must still go on, before its Plane can pass thro' the Sun, and must describe the Angle  $dBf$ . And therefore, all the solar Days are longer than the *Time* of one Revolution round the Earth's Axis. If the Planes of all the Meridians were perpendicular to the Plane of the Earth's Orbit, and the Earth described this Orbit with an equal Motion, after any Meridian had compleated its Revolution, because MD and  $md$  are parallel, the Angle  $dBf$ , would be equal to the Angle BSA, and the Arches  $df$  and AB similar: And because the *Times* are always equal, the Arch AB, and the Angle  $dBf$ , would constantly be of the same Quantity, and all the solar Days would be equal to one another; and then the apparent and equal *Time* would agree. But neither of these two Cases have Place in Nature; for the Earth does not proceed in its Orbit with an equal Motion; but in its *Aphelion* it describes a less Arch, in its *Perihelion* a greater. And moreover, the Planes of the Meridians are not perpendicular to the Ecliptick, but to the *Æquator*: And therefore, the *Time* of the angular Motion  $dBf$ , which, besides the intire Revolution, is to be added to the Space of a solar Day to compleat it, is not always of the same Quantity; whence the solar Days will not be equal.

*It is proved that the Solar Days are unequal.*

*The same is made plain by the apparent Motion of the Sun.*

BUT perhaps this may appear plainer, if we pass from the real Motion of the Earth, and consider the apparent Motion of the Sun; for it is by



by his apparent Motion, that we measure the *Apparent Time*. And therefore you must observe, that the natural solar Day, is that Space of *Time*, in which, by the Revolution of the whole Heavens, which is called the Revolution of the *Primum Mobile*, or of the first moveable Orb, the whole Circumference of the *Æquator* passes through the Meridian; and also so much more of the same Circle, as answers to the apparent Motion of the Sun to the East, in the mean while.

BUT the Arch of the *Æquator* passing thro' the Meridian, is not always equal to the correspondent Arch of the Ecliptick, which passes thro' the same, in the same Time; but is sometimes bigger, and sometimes less than it, even tho' the Sun's Motion were equal in the Ecliptick: The Difference between them arises from the oblique Position of the Ecliptick to the *Æquator*, as is plain by the Figure. Suppose  $\gamma \text{ } \textcircled{S}$  a Quadrant of the Ecliptick, and  $\gamma \text{ } \textcircled{E}$  a Quadrant of the *Æquator*. Suppose the Arch  $\gamma \text{ } A$  to be one Degree, which is nearly equal to the diurnal Motion of the Sun in the Ecliptick; for this mean Motion is  $59' 8''$ . Let  $AB$  be an Arch of the Circle of Declination, passing thro' the Sun in  $A$ , and intercepted between the *Æquator* and the Ecliptick. In the right-angular Triangle  $\gamma \text{ } BA$ , having the Side  $\gamma \text{ } A$  1 Degree, and the Angle  $A \gamma \text{ } B$ , which is the Inclination of the Ecliptick to the *Æquator*, and is nearly  $23\frac{1}{2}$  Degrees, we shall find the Side  $\gamma \text{ } B$   $55' 1''$ , almost  $5'$  less than the Arch  $\gamma \text{ } A$ . Again, suppose the Arch of the Ecliptick  $\gamma \text{ } C$   $89^\circ$ . From thence we shall find the Arch of the *Æquator*  $\gamma \text{ } D$ ,  $88^\circ, 54' 34''$ ; but when the Arch of the Ecliptick  $\gamma \text{ } \textcircled{S}$  is 90 Degrees, then  $AE$ , the correspondent Arch of the *Æquator*, is also 90 Degrees. And the Difference of the Arches  $\gamma \text{ } C$ ,  $\gamma \text{ } D$  is  $1^\circ 5' 26''$ . And the Difference of the Arches of the *Æquator*  $\gamma \text{ } B$  and  $DE$  is  $10' 25''$ , altho' the Arches of the Ecliptick  $\gamma \text{ } A$  and  $C \text{ } \textcircled{S}$ , which answer to them, are equal. From which it is evident, that the Arches

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XXV.

The diurnal  
Arches of  
the *Æqua-*  
tor are not  
equal to the  
diurnal Ar-  
ches of the  
Ecliptick.

Tab. XXIV.  
Fig. 2.



Lecture of the *Æquator*, answering to equal Arches of the  
 XXV. *Ecliptick*, are unequal: And therefore the diurnal  
 ~~~~~ Arches of the *Æquator*, which pass through the  
 Meridian, are unequal; but they measure the solar
 Days: Wherefore the solar Days are unequal.

*The second
 Cause of the
 Inequality
 of Days.*

BUT the Obliquity of the *Ecliptick* is not the
 only Cause of the Inequality of Days; for the
 very apparent Motion of the Sun in the *Ecliptick*
 is unequal; for he proceeds more slowly, and
 stays longer in the Northern Signs than in the
 Southern, by eight entire Days: And therefore, if
 there were no Obliquity of the *Ecliptick*, by this
 Cause alone, the diurnal Arches of the *Æquator*
 could not be equal. And therefore, their Inequality
 will be much greater, upon Account of these two
 Causes concurring together; that is, the unequal
 Motion of the Sun, and the Obliquity of the *Ec-*
liptick, which tho' they are sometimes contrary
 to each other, and so diminish the Inequality; as
 it happens when the Arches of the *Æquator* de-
 crease, on the Account of the Obliquity of the
Ecliptick, but by Reason of the Sun's approaching
 the *Perigæan* they increase, and on the contrary:
 Yet sometimes these two Causes concur to in-
 crease the Inequality, and neither of them depend
 one on the other, but each of them by itself has its
 Effect.

SINCE therefore the apparent Motion of the
 Sun to the East is unequal, it cannot be a fit
 Measure of *Time*, which should always go on at
 the same Rate. And therefore the natural and ap-
 parent Days are no ways to be applied to measure
 the celestial Motions, which do not depend upon
 the Motion of the Sun: Therefore the *Astronomers*
 found it necessary, instead of these solar Days, to
 substitute in their Place others that were equal,
 and a Mean between the shortest and the longest;
 and by them to distinguish the celestial Motions.
 And when these Motions have been computed
 according to the *Equal Time*, it is necessary to
 turn that *Time* again into the *Apparent Time*,
 that these Motions may be observed by us who
 measure

measure and number our *Times*, by the apparent Motion of the Sun. And on the contrary, if any Appearance in the Heavens, as for Example, an Eclipse, were observed according to the *Apparent Time*, and according to it the *Astronomical Tables* were to be examined, to see if they did agree with it or not; it will be necessary to turn the *Apparent Time* into *Equal Time*, otherwise the observed *Phænomenon*, will differ from that which is found by Computation.

BECAUSE we know no Body in Nature, which preserves constantly a perfect uniform Motion; and yet such a Motion, is only proper to measure equal Days and Hours; it is convenient to imagine some Body or Star, which moves in the *Æquator* Eastward, and which never quickens or slackens its Pace, but goes thro' the *Æquator*, in precisely the same Time, as the Sun finishes his Period in the *Ecliptick*. The Motion of such a Star, will rightly represent equal Time, and its diurnal Motion in the *Æquator* will be daily $59' 8''$, the same as is the mean Motion of the Sun in the *Ecliptick*: And therefore, the equal and middle Day is to be determined by the Arrival of this Star to the Meridian, and is equal to the Time in which the whole Circumference of the *Æquator*, or 360 Degrees, passes the Meridian; and besides that $59' 8''$: And because this Addition of $59' 8''$ always remains the same, all these mean Days will be constantly equal to each other.

SINCE the Sun goes unequally Eastward according to the *Æquator*, sometimes it will come to the Meridian sooner than this imaginary Star, and sometimes he will touch it later than it does; and the Difference is that which is between the *True* and *Apparent Time*. And this Difference is known by having the Place of the imaginary Star in the *Æquator*, and the Point of the *Æquator*, which comes to the Meridian with the Sun; for the Arch intercepted between them, being converted into *Time*, shews the Difference between *Equal* and *Apparent Time*, which is called the *Equation* of Time.

The Equation
of Time.

Lecture of Time. And it is the *Time* that flows, while
 XXV. the Arch of the $\mathcal{A}$ equator intercepted between the
 ~~~~~ Point determining the Right-Ascension of the Sun,  
 and the Place of the imaginary Star passes the Me-  
 ridian.

LET  $\mathcal{A}Q$  be a Portion of the Equinoctial,  
 EC of the Ecliptick, in which imagine S to be  
 the Place of the Sun, SA a Circle of Declina-  
 tion passing through the Sun, and meeting with  
 the  $\mathcal{A}$ equator in A, which will be the Point which  
 comes to the Meridian with the Sun. Suppose  
 $m$  to be the Place of the imaginary Star, which  
 performs its Period in the  $\mathcal{A}$ equator, with an equal  
 Motion: And when the Sun has arrived at the  
 Meridian, our imaginary Star will be distant from  
 it, by the Arch  $mA$ ; and if the Point  $m$ , be East-  
 ward of the Point A, it will come later to the  
 Meridian than it, and the apparent *Time* will be  
 faster than the mean; but if the Place of the  
 Star  $m$ , be more Westerly than A, it will sooner  
 arrive at the Meridian, and the *Apparent Time*  
 is slower than the Mean. And the Arch of the  
 $\mathcal{A}$ equator  $Am$ , converted into *Time*, is the Equa-  
 tion; which being added to, or substracted from  
 the *Apparent Time*, gives the true, according as  
 the Point  $m$  is to the East or West of the Point  
 A; and then we have the true *Time*. For to  
 know the Position of the Point A, in respect of  $m$ ,  
 and the Quantity of the Arch  $Am$ , take in the  
 $\mathcal{A}$ equator the Arch  $\mathcal{V}S$  or  $\mathcal{Q}S$ , equal to the  $\mathcal{V}S$   
 or  $\mathcal{Q}S$  in the Ecliptick; and then the Arch  $sm$ ,  
 will be the Distance between the true and mean  
 Place of the Sun, which therefore is given by  
 the Sun's Anomaly; but the Arch  $As$  is the Diffe-  
 rence between the *Hypothenuſa*  $\mathcal{V}S$ , of the right-  
 angled Triangle  $\mathcal{V}SA$ , and its Side or Base  $\mathcal{V}A$ ,  
 which may be found by *Trigonometry*. Moreover,  
 the Arch  $Am$  is equal to either the Sum or Diffe-  
 rence of the Arches  $As$  and  $sm$ ; and therefore  
 when they are known, the Arch  $Am$  will be like-  
 wise known.

The Equati-  
 on of Time  
 consists of  
 two Parts.

MOREOVER



MOREOVER we must observe, that in the first and third Quadrant of the Ecliptick, the Point  $s$  falls upon the East-side of the Point  $A$ : And therefore the Arch  $As$ , being turned into *Time*, is to be subtracted; because the Point  $S$  comes later to the Meridian than the Point  $A$  does. But in the second and fourth Quadrants, the Point  $s$  is more Westerly than  $A$ , and arrives at the Meridian before it: And therefore, the Arch  $As$ , turned into *Time*, is to be added, to get the *Time* when the Point  $S$  arrives at the Meridian. Suppose, for Example,  $As$  be two Degrees, as it is when the Sun is in the 20th Degree of  $\gamma$ ; this Arch, turned into *Time*, is 8 Minutes: And therefore, we must add 8' to the *Apparent Time*, to have the *Time* when the Point  $S$  comes to the Meridian.

MOREOVER, in the first Semicircle of Anomaly, that is, while the Sun in this present Age, goes from the seventh Degree of  $\mathfrak{z}$ , to the seventh of  $\mathfrak{w}$ , the mean Motion of the Sun is greater than its true Motion; therefore, then the middle Place precedes the true Place. And therefore, in all that Semicircle the Point  $m$  will be to the East of the Point  $s$ ; and the Arch  $ms$ , turned into *Time*, is to be subtracted from the *Time* that the Point  $S$  reaches the Meridian: But in the other Semicircle of Anomaly, after the Sun has left the *Perigæan*, or rather the Earth the *Perihelion*, the mean Motion is less than the true, and then the mean Place follows the true; and consequently, the Point  $m$  is to the West of the Point  $S$ , and comes sooner to the Meridian than it does: And therefore the Arch  $ms$ , turned into *Time*, is to be added to the *Time* in which  $S$  touches the Meridian. Having now the Distance of *Time*, between the Coming of the Point  $m$  to the Meridian, and the Coming of the Point  $S$  to the same; as also the Distance of *Time*, between the Arrivals of the Points  $s$  and  $A$  to the Meridian, we shall have the Distance of *Time*, between the Coming of the Point  $m$  to the Meridian, and of the



Lecture XXV. the Point A's Arrival to the same; that is, we shall have the Difference between the *Apparent and True Time*, which is the *Equation of Time*.

Two Tables  
for equating  
Time.

FOR the equating of *Time*, the *Astronomers* compose two Tables; one for the Arch  $s m$ , which is to be entered into with the Anomaly of the Sun: And if the Point  $m$  be Westward of the Point  $s$ , they mark it with  $+$  or the Sign of Addition; but if it be on the other Side, they place  $-$  or of Subtraction. The other Table is for the Arch  $s A$ , which is the Difference between the Place of the Sun in the Ecliptick, and his Right-Ascension. And the Equations of this Table are likewise marked with the Signs of Addition or Subtraction, as the Point  $s$  is to the West or East of the Point A. The Sum of these two Equations, if they be of the same Kind, that is, both to be added, or both to be subtracted; or their Difference, if their Affections be of different Kinds, make up the absolute *Equation of Time*.

The Tempo-  
rary Table.

THE Artists likewise make a Table composed of both the former; but it will only serve for a Time: Yet it may be used for a whole Age without any sensible Error; for the same Degree of Anomaly keeps nearly in the same Degree of the Ecliptick, the Space of an Age: And therefore, for the Space of 50 Years these two Equations may be joined in one. But because of the Precession of the Equinoxes, the Sun's *Apogæan*, in Process of Time, changes its Place in the Ecliptick, and goes Easterly with the Fixed Stars: And therefore, in different Ages, the same Degrees of Anomaly will fall upon different Degrees of the Ecliptick: And therefore, one Table will not serve for all Ages.

When the  
solar Days  
begin to be  
longer than  
the mean.

THE imaginary Star, by whose equal Motion we measure Time, goes constantly and uniformly forward to the East: But the Point A, which determines the Right-Ascension of the Sun, and marks out the apparent Time, has as it were a Libration, or goes backwards and forwards in respect



respect of *m*: Sometimes it gets to the East of *m*, and sometimes is to the West of it, and sometimes coincides with it. And therefore, when the Point A has its relative Motion in respect of *m* Eastward, the Point A is more East than the Star *m*, and then the Days are longer than the mean Days, which are measured by *equal Time*; and the faster the Point A goes to the East, so much the longer are the solar Days: For, besides the Revolution of the whole Heavens, the Arch to be added, to make up the solar Day, is greater; because the Point A goes a greater Space Eastward. Hence it follows, that as soon as the relative Motion of the Point A begins to be Eastward, the solar Days begin likewise to be longer than the mean Days. I speak of the relative Motion in regard of the Point *m*; for the absolute Motion of A is always Eastward: But when the Point A, is gone its farthest Distance from *m* to the East, then it begins to come back again to *m*, and has its relative Motion Westward: But before that, the Point A will be for a while stationary in respect of *m*, in the middle Time between its Recess and Access; and then the solar Days will be equal to the mean Days; and in these Points the Equations will be greatest. *When the mean and solar Days are equal.* When the Motion of the Point A, to the East, is quickest, there the Days become the longest; and where it is the slowest, that is, where the Motion relative to *m* is Westward, and greatest, there the Days are shortest. In the present Age wherein we live, when the Sun is in the 10th Degree of *Scorpio*, the Point A is at its farthest Distance from *m* to the West of it; and its Distance then amounts to  $4^{\circ} 2' 45''$ , and therefore the greatest Equation in Time, is  $16' 11''$ . From thence, the Days begin to increase, till the Sun comes to  $22\frac{1}{2}$  Degree of *Aquarius*, where it has gone to its farthest Distance from *m* Eastward, it being there removed 3 Deg.  $42\frac{1}{2}$  Min. whence the greatest Equation of Time is  $14' 50''$ : And from thence, the relative Motion of the Point A begins again to be Westward, till the Sun comes to the 24th Degree of *Taurus*, or the *Bull*;



Lecture Bull; and there the Point A is removed from *m* 1  
 XXV. Deg.  $1\frac{1}{2}$  Min. to the West of the Star *m*, and the  
 ~~~~~ greatest *Equation* of Time is  $4' 6''$ . Thence it re-  
 turns again to *m*, and moves Easterly, till the Sun
 comes into the $3\frac{1}{2}$ Degrees of the *Lion*; where A
 is distant from *m* 1 Deg. $28\frac{1}{2}$ Min. and the greatest
Equation of Time is $5' 53''$: And from thence its
 Motion begins to be to the West, till the Sun arrives
 at the 10th of the *Scorpion*; and thereabouts it changes
 its Course and goes Eastward. It is plain, that when
 the Points A and *m* coincide, that there the mean
 and *apparent Time* must likewise coincide. Hence,
 if we have a Pendulum Clock, accurately and nicely
 fitted, and the Motion of the Hand set to equal or
true Time, the Hand of this Clock will always point
 out the *Time* different from the solar *Time* shewed by
 a Sun-Dial; except four Times a Year, which is
 about the 4th of *April*, the 6th of *June*, the 20th
 of *August*, and the 13th of *December*. At all other
 Times, the Hour, by the Sun-Dial, will either be
 before, or later than that shewed by the Hand of
 the Clock: And about the 23d of *October*, the
 Clock will differ most of all from the Sun,
 where its Motion is slower than the solar *Time* by
 $16' 11''$.

IF you inquire in what Points the *Equations* are
 the greatest, the eminent Dr. *Edmund Halley*, who
 for his great Inventions is never to be mentioned
 by *Astronomers* without Honour, has given us the
 Solution of this *Problem*. But to understand it, we
 must first lay down the following *Lemma*.

LEMMA.

IF any plain Figure be projected orthographically
 on a Plane; which is done by letting fall, from every
 Point of it, Perpendiculars on the Plane of Projection;
 the Area of that Projection of the Figure, will be to
 the

the Figure projected, as the Co-sine of the Inclination of the Planes is to the Radius.

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FOR any Figure can always be resolved into Parallelograms, or Triangles, whose Bases are parallel to the common Section of the Planes; and therefore, they will be parallel to the Plane on which they are projected: Wherefore, the Bases of these Parallelograms, or Triangles, and their Projections on the Plane, are always equal to each other, and parallel, as we have shewed in *Lecture XIII.* But the Perpendiculars let fall from the Summits, or Tops of the Triangles, and Parallelograms upon the Bases, are also perpendicular to the common Section of the Planes, by the 29th of the first *El.* And therefore, the Inclination of the Perpendiculars to the Plane is equal to the Inclination of the Planes to each other. And consequently, the Projections of these Perpendiculars will be to the Perpendiculars themselves, as the Co-sine of the Inclination of the Plane is to the Radius. Wherefore, every Parallelogram, or Triangle, is projected into another, whose Base is equal to the Base of the Triangle, or Parallelogram projected; and its Height is to the Height of the Figure projected, as the Co-sine of the Inclination of the Planes is to the Radius. But Triangles, and Parallelograms, whose Bases are equal, are as the Perpendiculars let fall from the Tops upon the Bases. The Projection therefore, of each Triangle, is to the Triangle projected, in a constant and given Proportion; consequently, all the Projections of all the Triangles, or Parallelograms, are to the Figures projected in the same Proportion; that is, the Projection is to the Figure projected, as the Co-sine of the Inclination is to the Radius.

IF the Orbit of the Earth be orthographically projected on the Plane of the *Æquator*, by letting fall from each of its Points Perpendiculars, the Projection will be an Ellipse, in whose Perimeter the Extremity of a right Line, let fall from the Earth perpendicular to the Plane of the *Æquator*, will

Lecture constantly move: And this Point, by its Motion, will mark out the right Ascension of the Earth, or its Motion, according to the $\mathcal{A}$ Equator, as it is to be seen from the Sun; to which the right Ascension of the Sun, seen from the Earth, is always equal.

Plat. XXIV. Let $\mathcal{V} A \mathcal{C}$ be the Ellipse in which the Orbit of the Earth is projected, S the Point of Projection of the Sun's Center, $\mathcal{V} S$ the common Intersection of the $\mathcal{A}$ Equator and the Ecliptick, A any Point, where a Perpendicular from the Earth meets with the Projection: The Angle $\mathcal{V} S A$ will measure the right Ascension of the Sun. Now, I say, that this Point A , which marks out the Motion of right Ascension, will so proceed in the Ellipse $\mathcal{V} A \mathcal{C}$, that it will describe about the Point S , elliptick Area's proportional to the Times. For, in a given Time, let A move through the elliptick Arch $A B$; draw the Lines $A S$, and $B S$; and the trilineal Figure $A S B$ will be the Projection of the correspondent Area, which the Earth describes in the Plane of the Ecliptick, in the same Time, round the Sun: And therefore, the Projection $A S B$, will be to the correspondent Area in the Earth's elliptick Orbit, as the Co-sine of the Inclination of the $\mathcal{A}$ Equator, and the Ecliptick, is to the Radius. But in the same Proportion is the whole elliptick Area $\mathcal{V} A \mathcal{C}$, to the whole Area of the Earth's Orbit: Therefore, by Permutation of Proportion, the trilineal Figure $A S B$ will be to the whole elliptick Area $\mathcal{V} A \mathcal{C}$, as the Area, described in the Earth's Orbit round the Sun, is to the whole Area of the Earth's Orbit; that is, as the Time in which that Area in the Orbit of the Earth, or the Area $A S B$ in the Projection, as described, is to the whole periodical Time. Therefore, the Point A moves in the Perimeter of the Ellipse at such a Rate, that it describes, about S , Areas that are continually proportional to the Times.

THE same Things being laid down; at the Center S , and Distance $S A$, which is a mean Proportional between half the greater, and half the lesser Axis of the Ellipse, describe a Circle; this Circle will be equal

equal to the whole elliptick Area; as it is easy to demonstrate from the Doctrine of the *Conick Sections*: This Circle will cut the Ellipsis in four Points E, F, G, H: The Points of Intersection shew the right Ascensions of the Sun, where the Equations are greatest. Imagine a Point M, to move uniformly in the Periphery of the Circle; its Motion will then represent the Motion of our imaginary Star *m*, and will describe about the Point S, circular Sectors that are proportional to the Time: And because the Area of the whole Circle, and the Area of the Ellipse, are equal, the Area's of the elliptick Sectors, and of the circular Sectors, described in the same Time, will be constantly equal. Let us now suppose, that the Point M, in the Periphery of the Circle, and the Point that marks out the Sun's right Ascension in the Ellipse, be placed at the same Time both in the right Line S L M. Let these Points afterwards be in *m* and A, then the elliptick Area L S A will be equal to the circular Sector M S *m*: And because the Arch M *m* is without the Ellipse, the Angle M S *m* will be less than the Angle M S A, and the Difference of the Angles measured by the Arch *m* A, which is the *Equation of Time*. When the Point, which marks out the right Ascension of the Sun, comes to the Intersection F of the Circle and Ellipse; there its angular Motion round the Sun will be equal to the angular Motion of the Point *m*; for the Area's *m* S *n*, and A S F, are equal, they being both described in the same Moment of Time, and at the same Distance from S; and consequently, the Arch *q* F, is equal to the Arch *m* *n*. In the Point therefore, F, the Motion of right Ascension, is equal to the Motion of the imaginary Star, or equal to the mean Motion. The same Thing may be shewed at G, H, and E: But it was shewed before, that where the Motion of right Ascension was equal to the Motion of the Point *m*, that there the Equations are greatest. Wherefore, in the Points F, G, H, and E, are the Equations greatest.

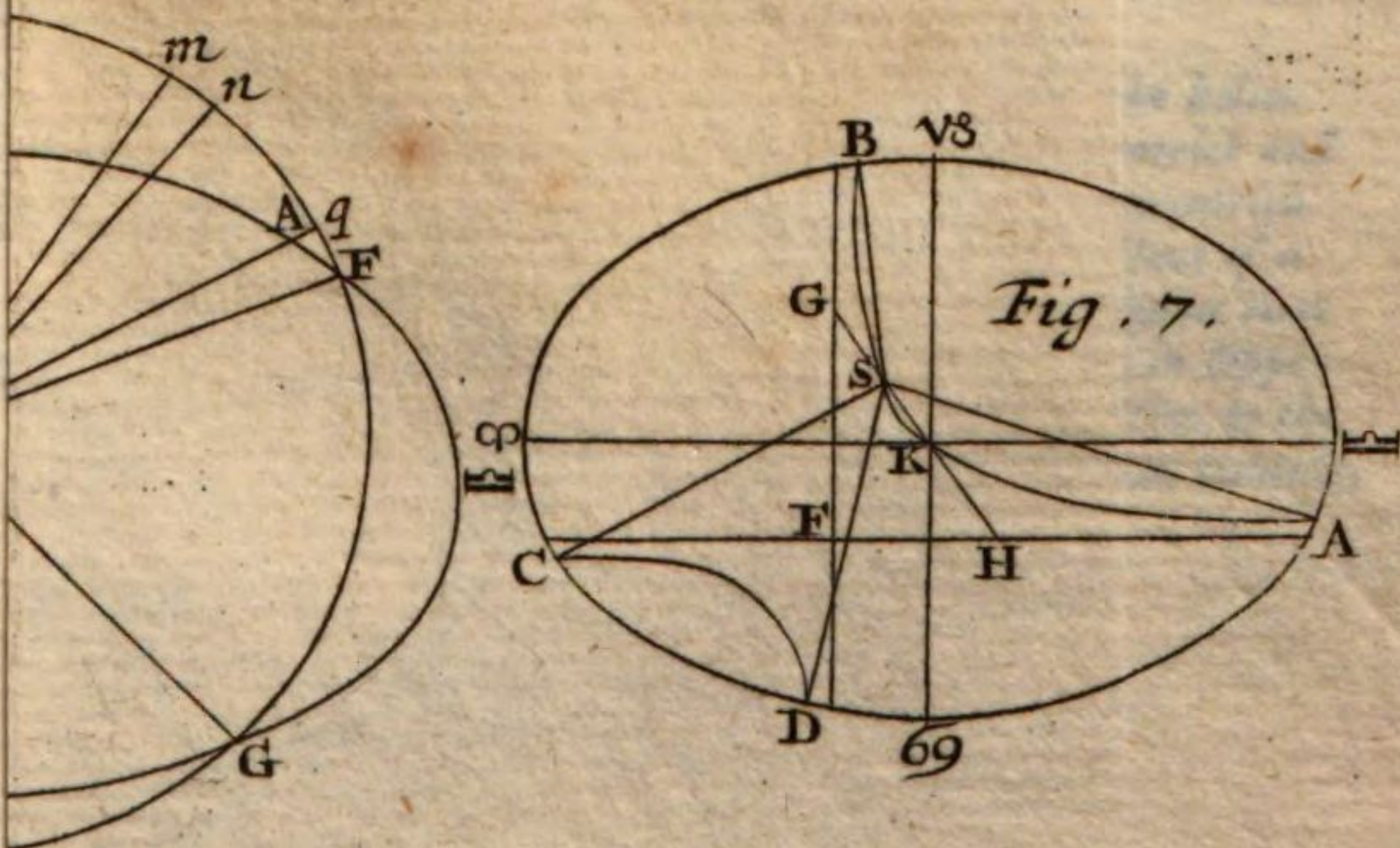
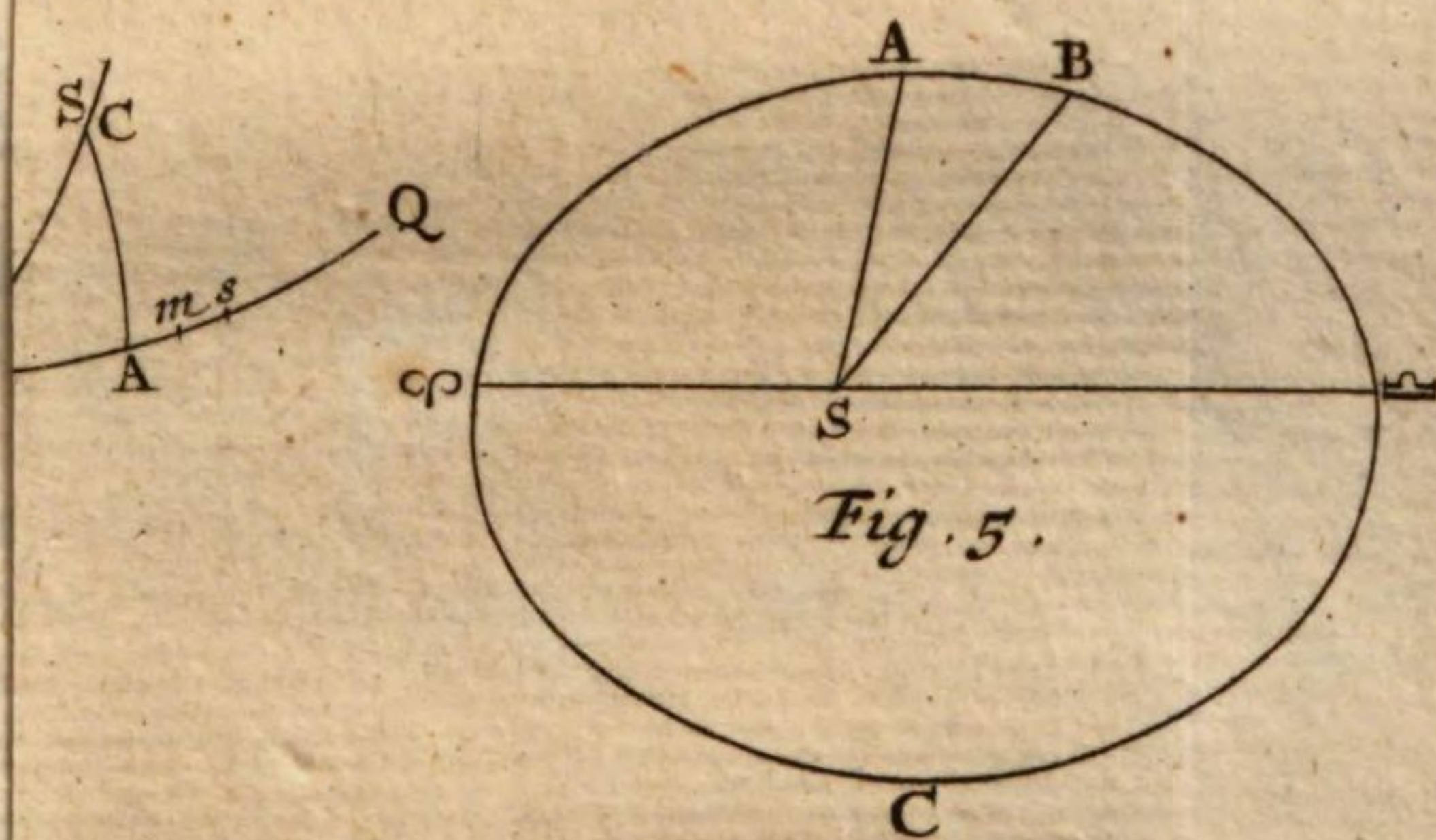
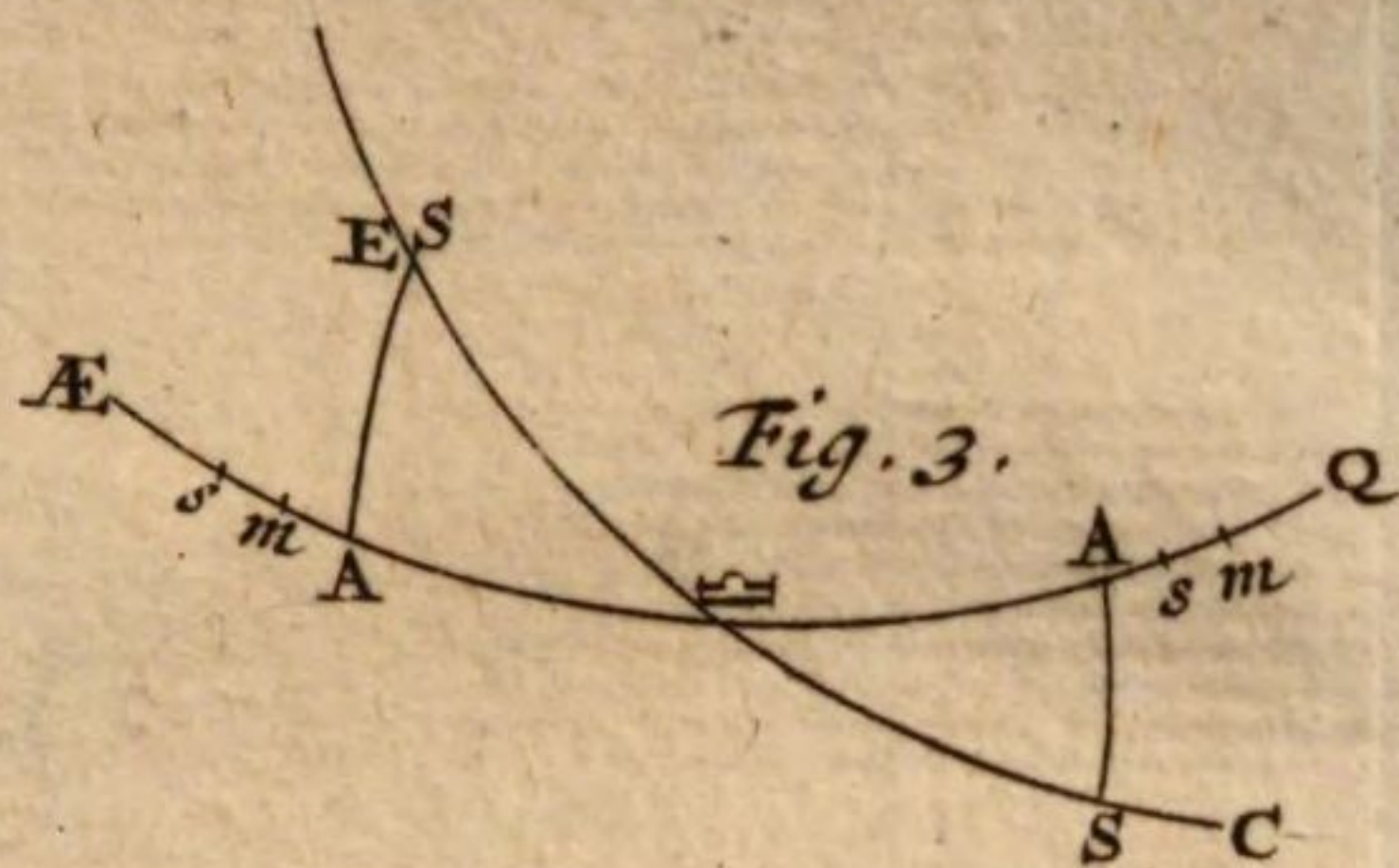
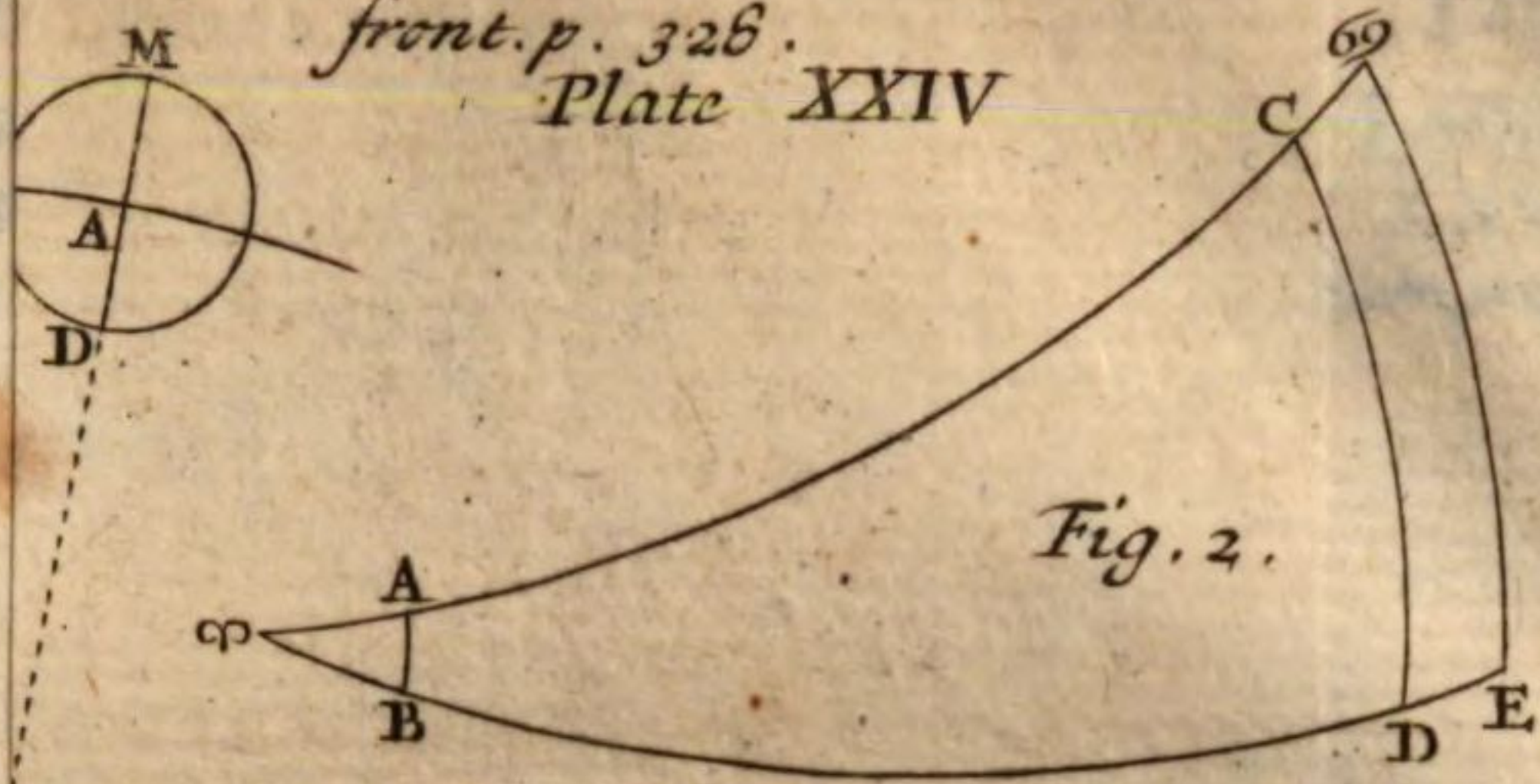
Plat. XXIV.
Fig. 6.

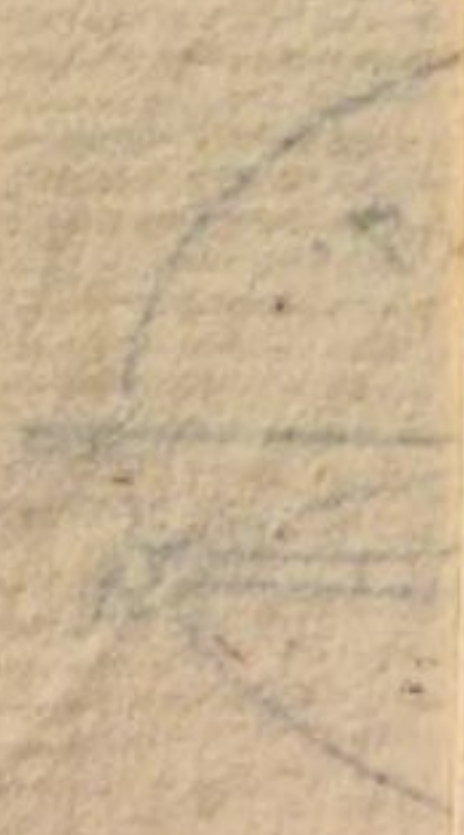
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Which are
the Points of
the Ecliptick
where the
Days are
longest, and
where
shortest.

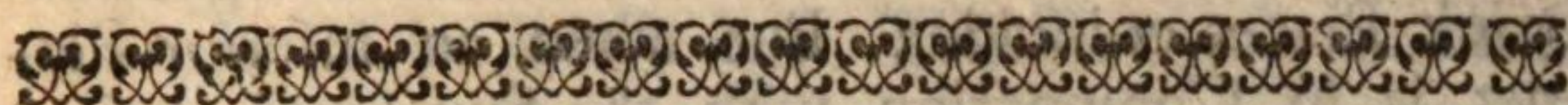
Plat. XXIV.
Fig. 7.

IF you inquire in what Points the Days are longest or shortest, the same eminent Dr. *Halley* has also given us a geometrical Solution of this Problem. Let $\gamma \text{ } \text{---} \text{ } \omega$ be the Ellipse into which the Earth's Orbit is projected, and S the Point of the Sun's Center, K the Center of the Ellipse. Produce KS on each Hand, so that KG and SH, may be to KS (which is the Projection of the Eccentricity) as the Square of the Radius is to the Square of the Sine of the Obliquity of the Ecliptick: Thro' K draw $\gamma \text{ } \text{---} \text{ } \omega$ parallel to the common Section of the *Æ*quator and Ecliptick, and cut it at right Angles with the Line $\text{---} \text{ } \omega$ K ω : Thro' G draw GF, and thro' H, draw FH, parallel to the Lines $\text{---} \text{ } \omega$ and $\gamma \text{ } \text{---} \text{ } \omega$; and thro' S and K describe the Hyperbola AB, whose Asymtots are FG, FH. This Hyperbola, and its opposite CD, will cut the Ellipse in the Points that are required; that is, when the Sun is in the Points of the Ecliptick which correspond with B and D, then the Days are the longest; and in B the Days are longer than in D: But the Points of the Ecliptick, which answer to A and C, give us the Places where the Days are shortest. The Demonstration of this depends on the Motion of the Point that marks the right Ascension of the Sun round S; for it describes about it Area's that are proportional to the Times. Therefore, the angular Velocity is every where reciprocally as the Square of the Distance from S; consequently, the Velocities must be greatest where these Distances are least; that is, where the least Lines that can be drawn from S fall upon the Ellipse; and the Velocities are the least, where the Lines drawn from S to the Ellipse are the greatest: But by the Construction, and the 62d Prop. Lib. V. of *Apollonius's Conicks*, it is evident, that the Hyperbola's will cut the Ellipsis in the Points A and C; where the right Lines SA and SC are the greatest; and in the Points B and D, where the right Lines SB and SD are the least: For in these Points the Lines SA, SB, SC, SD, are perpendicular to the Curve. Hence the Motion





tion of the Sun, according to his right Ascension, will be quickest in B and D ; and therefore the Days will be then the longest ; and the Motion being slowest in C and A, the Days will be there the shortest.



LECTURE XXVI.

Of the Theories of the other Planets.

AFTER having explained the Theory of the Earth's annual Motion, and shewed the Methods by which the Form of its Orbit, and the Position of the *Apsides* are determined, we may then, by the Help of *Astronomical* Tables, compute for any Time, the Place of the Earth in the Ecliptick seen from the Sun, and its opposite Point in which the Sun appears to be, as he is observed by us. We will now come to explain the Theories of the other Planets ; the Knowledge of which cannot be attained without the Earth's Motion being perfectly known.

BUT the Periods of the Planets, or the Times they take to complete their Circulations, are to be found out in the first Place. For which Purpose we must observe, that when any superior Planet comes to an Opposition with the Sun, they then appear in the same Point of the Ecliptick, seen from

*The helio-
centrick and
geocentrick
Place of a
Planet that
is in Oppo-
sition to the
Sun coincide.*

Lecture from the Earth, as they would do if the Eye
 XXVI. were in the Sun, and observed them from thence ;
 as also the inferior Planets, when they are in Con-
 junction with the Sun, and are observed in the
 Sun's Disk : If there were an Observer in the
 Sun, he would see them in the opposite Point of
 the Ecliptick, in which we behold them : And
 therefore, whenever a superior Planet is in Oppo-
 sition to the Sun, his heliocentrick and geocen-
 trick Places coincide : But when an inferior Pla-
 net is in Conjunction with the Sun, and is seen
 in his Disk, the heliocentrick and geocentrick
 Places are opposite to each other. Moreover, in
 the inferior Planets, when they are at their great-
 est Elongations from the Sun, the Angle at the
 Sun's Center, contained between the right Lines
 drawn to the Earth and Planet, is nearly the Com-
 plement of the Elongation : For in Orbits which
 are nearly circular, a Line touching the Orbit is
 almost perpendicular to the Line drawn from
 the Sun to the Point of Contact : And therefore
 that Angle will be given. But we have the Point
 of the Ecliptick, in which the Earth is at that
 Time, seen from the Sun ; and consequently, the
 Point of the Ecliptick in which the Planet is,
 seen from the Sun. And therefore, in these Po-
 sitions, we have the heliocentrick Places of the
 Planets.

*How to find
 nearly the
 periodical
 Time of a
 Planet.*

IF then any superior Planet, as for Example
Jupiter, were observed when he is in Opposition
 to the Sun : And again, if he were likewise ob-
 served when he comes next in Opposition to the
 Sun ; we shall have that Arch which the Planet,
 seen from the Sun, has in the mean Time de-
 scribed. Say, as that Arch is to the whole Cir-
 cumference, so is the Time between the Obser-
 vations to a Fourth, which will be nearly the peri-
 odical Time of the Planet. After the same Man-
 ner, by observing two heliocentrick Places of an
 inferior Planet, we may nearly collect its peri-
 odical Time. I say nearly, and not exactly ; for
 the

the Calculation supposes, that the Motion of the Planet is in a Circle, and that thro' the whole Period it is uniform, which is not true.

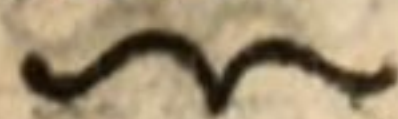
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THE following Method for finding the periodical Time is more accurate. Observe a Planet twice successively in the same Node; that is, let there be two Observations, when the Planet about the same Part of its Orbit, has no Latitude, which can only happen when the Planet has really no Latitude, and is placed in its Node: The Time between the two Observations will be equal to the periodical Time of the Planet. For, because all the Planets move in Orbits, whose Planes are different from the Plane of the Ecliptick, and the Sun is in the common *Focus* of all the Orbits, these Planes will all cut the Ecliptick, in Lines which pass thro' the Sun, and in the Intersections of these Lines with the Ecliptick are the Nodes; and the Planet in the whole Time of its Period, can never be observed but once, in one and the same Node. Now the Nodes are either at rest, or they have a very slow Motion, so that for the Space of one Period, they may be esteemed as at rest. And therefore, if we know the Time between two Arrivals of a Planet at the same Node, immediately following each other, we shall likewise know the Time of a Planet's Period.

A more accurate Method of finding the same.

By the very same Observations, if we have the Theory of the Earth's Motion, we can find the Position of the Line of the Nodes, or the Points of the Ecliptick, in which that Line does intersect it. Let ATB , be the Orbit of the Earth, CND the Orbit of the Planet, NS the Line of the Nodes; and in the first Observation, suppose the Earth in T , and the Planet to be observed, in N : And because the Place of the Planet, seen from the Earth, is known by Observation, and the apparent Place of the Sun, at the Time, is known by the Theory of the Earth's Motion, we have the Arch of the Ecliptick, between the two Places, or the Measure of the Angle NTS . In the

Tab. XXV.
Fig. 1.

Lecture
XXVI.

*How to find
the Position
of the Nodes.*

*To find the
Inclination
of the Pla-
net's Orb to
the Eclip-
tick.*

Plate XXV.
Fig. 2.

the second Observation, let the Earth be in t , and the Planet in the same Node N , and we shall have, by the same Way, the Angle NtS . In the right-lin'd Triangle TSt , we have the Sides TS , tS , and the Angle $TS t$, which is known by the Theory of the Earth; therefore, by *Trigonometry*, we can find the Angles $ST t$, and StT , as likewise the Side tT : Therefore, from the known Angle $ST t$, take away the known Angle STN , and we shall have the Angle $NT t$. To the known Angle ntS , add the Angle StT , which was found out, and we have the Angle NtT . Then, in the Triangle NtT , we have all the Angles, and the Side tT ; consequently, we shall have the Side NT , the Distance of the Planet from the Earth, at the first Observation. Lastly, in the Triangle NTS , we have the Sides NT and TS , and the Angle NTS , which was known by Observation; consequently we shall find the Side NS , the Distance of the Planet from the Sun, when he is in the Node, and the Angle TSN , which shews the Position of the Line of the Nodes; for that Point of the Ecliptick which the Earth is in, seen from the Sun in the Time of the Observation, is known; and the Angle TSN is likewise known: Therefore we have the Point of the Ecliptick N , in which the Node is placed, seen from the Sun; and the Point n opposite to it will be the Place of the other Node. And therefore the Position of the Nodes is found.

THE Places of the *Nodes* being once determined, we shall easily find the Inclination of the Plane of the Planet's Orbit to the Ecliptick: For having the Places of the *Nodes*, we can find the Time when the Earth, seen from the Sun, is in one of them. At the same Time, observe the *geocentrick* Latitude of the Planet, and his Distance from the opposite *Node*: Then the *geocentrick* Latitude of the Planet is equal to the *heliocentrick* Latitude it will have, when seen from the Sun, at the same Distance from the *Node*; that is, make the Angle nSp , equal to the Angle nNP , and the Latitude

Latitude of the Planet at p , observed from S , will be equal to its Latitude at P , observed from N . For let CPD be the Orbit of the Planet, NS the Line of the Nodes, BNT a Portion of the Orbit of the Earth, in which suppose the Earth to be at N , in the Line of the Nodes, and the Planet in its Orbit to be at P ; and then the Sun, Earth and Planet, will be all in the Plane of the Planet's Orbit. From the Point P , on the Ecliptick's Plane, let fall the Perpendicular PE , and in the Plane of the Ecliptick, draw the Line NE ; then the Plane of the Triangle NPE will be perpendicular to the Ecliptick, and the Angle PNE will be the visible Latitude of the Planet, seen from the Earth. Through S , draw Spf , parallel to NP , and pe parallel to PE ; and the Plane through Sp , and pe , will be parallel to the Plane NPE , and consequently perpendicular to the Plane of the Ecliptick; and therefore Se , the common Section of the Ecliptick, with this Plane, will be parallel to NE . And because NP and NE are parallel to Sp and Se , the Angle pSe , the *heliocentrick* Latitude, will be equal to the Angle PNE , the Latitude of the Planet observed from the Earth, in the Node N .

LET nf be a Portion of the Planet's Orbit, extended to the Heavens, nb a Portion of the Ecliptick, fb a Circle of Latitude passing through the *heliocentrick* Place of the Planet. In the right-angled spherical Triangle $nf b$, having nb , the Distance of the Planet from the Node, equal to what was observed when the Earth was at N , and the Latitude fb , equal also to what was observed at N , we can find from thence the Angle $b n f$, the Inclination of the Plane of the Orbit to the Ecliptick, which was to be found out.

HAVING once found out this Inclination, by Observation we can find out the *heliocentrick* Place of the Planet, and his Distance from the Sun, when ever he comes in Opposition to the Sun.

LET

Lecture XXVI **How to find the heliocentrick Place and Distance from the Sun, when the Planet is in Opposition to the Sun.** **Plate XXV. Fig. 3.**

Let ATB be the Orbit of the Earth, DPE the Orbit of the Planet: Suppose the Planet in P , and the Earth in T , and NSn the Line of Nodes, in which the Sun is in S . The Planet being in Opposition to the Sun, its Place, reduced to the Ecliptick, will be in the Line ST , which passes through the Earth. Observe the Angle PTE , the Planet's *geocentrick* Latitude, and we have the Angle PST , his *heliocentrick* Latitude, because we have the Planet's Distance from the Node. Likewise, by the Theory of the Earth's Motion, we have ST , its Distance from the Sun. And therefore, in the Triangle PST , having all the Angles, and one Side ST , we shall find SP , the Distance of the Planet from the Sun; and the Angle PSn , the Distance of the Planet from the Node, is found by the *heliocentrick* Latitude; by which Means we have the Place of the Planet, in his own Orbit. In the same Manner, if we have any other two Observations of the same Planet, in a Position or Aspect opposite to the Sun, we shall have the Position and Magnitude of three Lines, thro' whose Extremities the Planet's Orb passes, and the Sun is in one of the *Foci* of the Orbit. And therefore, to determine this Orbit, its Form and Position, we must describe an Ellipse, whose *Focus* is given, and which will pass thro' three given Points. The *Geometers* shew the Method of constructing this Problem, and we will likewise give the Solution of it hereafter.

To find the heliocentrick Place and Distance, when the Planet is in any other Aspect. **Plate XXV. Fig. 4.**

THOUGH a Planet were not in an *achronical* Position, but in any other Aspect besides, in Opposition to the Sun; yet, by one Observation, its Distance from the Sun, and *heliocentrick* Place may be found. Suppose PAE the Orbit of the Planet, TGH the Orbit of the Earth. Let the Earth be in T , and the Planet in P , and the Sun in S , in the Line of the Nodes NS . From P , let fall the Perpendicular PB , on the Plane of the Ecliptick: Draw BT , and produce it, till it meets with the Line of the Nodes in N , and the Plane of the Triangle NPB will be perpendicular to the Plane of the Ecliptick. Let the Line CT , be also perpendicular

pendicular to it, and meet with the Plane of the Planet's Orb in C. From T, upon the Line SN, let fall the Perpendicular TD; join the Points D and C, and the Angle TDC will be the Inclination of the Planet's Orbit to the Ecliptick, which Angle is therefore given. Observe the Angle BTP, the Planet's *geocentrick* Latitude, and the Angle BTS, its Elongation from the Sun, according to the Ecliptick. In the Triangle NTS, from the Theory of the Earth, we have the Side ST, the Distance of the Earth from the Sun, and the Angle TSN, which is known by the Place of the Earth and *Node*, in the Ecliptick, as also the Angle STN, the Complement of the Angle STB to two Right Angles: Hence we shall have NT. In the right-angled Triangle TSD, having TS, and the Angle TSD, we shall find TD; and therefore, in the right-angled Triangle TDC, having TD, and the Angle TDC, the Inclination of the Orbit to the Ecliptick, we shall find the Side TC. In the right-angled Triangle TCN, we have TC and NT; and therefore, we can find the Angle TNC. And again, in the Triangle NTP, we have all the Angles; for the Angle NTP is the Latitude of the Planet found by Observation, or its Complement to two Right-angles, and the Angle PNT just now found, as also the Side NT; wherefore we shall find the Side TP. In the Triangle PTB, rectangular at B, we have the Side TP, and the Angle PTB, which is the Latitude observed; wherefore, we shall have the Sides BT and BP. And in the Triangle TSB, having TB and TS, and the Angle BTS, we shall have the Side SB, which is called the *curtate Distance* of the Planet from the Sun, as also the Angle TSB, and consequently, the *heliocentrick* Place of the Planet reduced to the Ecliptick. Lastly, In the Triangle PBS, we have the Sides PB, BS, and by them we shall have SP, the Distance of the Planet from the Sun, and the Angle PSB, the *heliocentrick* Latitude of the Planet. But having the *heliocentrick*

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centrick Latitude, and the Inclination of the planetary Orbit to the Ecliptick, we can find the Planet's Distance from the *Node*, and consequently, his *centrick* Place, seen from the Sun. If, by this Method, we find out two other *heliocentrick* Places of the Planet, and the Distances from the Sun, having likewise the *Focus* of the Orbit, which is the Center of the Sun, we may describe an Ellipse, which shall pass through the given Points, and be the Orbit of the Planet.

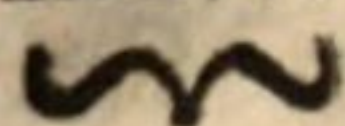
Dr. Halley's
Method of
determining
the helio-
centrick
Place and
Distance
from the Sun.
Plate XXV.
Fig. 5.

THE most ingenious Dr. *Halley* contrived another Method for finding out the central Places of the Planet, and its Distances from the Sun; which supposes only, that the periodical Time of the Planet is known. Let KLB be the Orbit of the Earth, S the Sun, P the Planet, or rather the Point in the Plane of the Ecliptick on which the Perpendicular let fall from the Planet meets that Plane. And first, when the Earth is in K , observe the *geocentrick* Longitude of the Planet, and having the Theory of the Earth, we have the apparent Longitude of the Sun; wherefore we have the Angle PKS . The Planet, after it has compleated an intire Revolution, does again return to the same Point P ; at which Time, suppose the Earth in L , and there again let the Planet be observed, and find the Angle PLS , the Elongation of the Planet from the Sun. Having the Times of the Observations, we have the Places of the Earth in the Ecliptick, or the Points K and L , and consequently, the Angle LSK , and the Sides LS and SK ; wherefore we shall have the Angles SKL and SLK , and the Side LK . From the known Angles SKP and SLP , take away the known Angles SKL and SLK , and we shall have the Angles PKL and PLK known; therefore, in the Triangle PLK , having all the three Angles, and the Side LK , we shall find the Side PL ; and, in the Triangle PLS , having the Sides PL and LS , and the intercepted Angle PLS , we shall

shall have the Angle LSP , which determines the *heliocentrick* Place, and its Distance from the *Node*, according to the *Ecliptick*, as also the Side SP . But, as the Tangent of the *geocentrick* Latitude is to the Tangent of the *Heliocentrick*, so is the *curtate Distance* of the Planet from the Sun to its *curtate Distance* from the Earth. But, by Observation, we have the Planet's *geocentrick* Latitude, wherefore its *heliocentrick* Latitude will also be found. By which, and the *curtate Distance* of the Planet from the Sun, we can find out the true Distance which was wanted. If, by this Means, we acquire three *heliocentrick* Places of the Planet, and the correspondent Distances from the Sun, we shall have the Form of the Orbit, and the Position of the *Apsides*, by describing an Ellipse, which shall pass through three given Points. This *Ellipsis* is determined by the following Method.

LET SD , SC and SB , be three Lines given in Magnitude and Position. Draw DC and BC , and produce them, so that DF may be to CF , as DS is to CS ; and also CE to BE , as CS is to BS . Join FE , on which, from S , let fall the Perpendicular SG , which will give the Position of the Axis. Draw the Lines DK , Ci and BH ; and cut SG in A , and produce it, so that GA may be to SA , as KD is to SD ; and also $G a$ be to $S a$, in the same Proportion; and make $s a$ equal to SA . And the Points A and a are the *Vertices* or *Apsides* of the Orbit, whose *Foci* are S and s , and greater Axis $A a$; and if, with these *Apsides* and *Foci*, we describe an Ellipse, it will be of the same Form with the Orbit of the Planet. For, because SD is to CS , as FD is to FC , and so DK is to Ci ; by Change of Proportion, DS is to DK , as CS is to Ci , and so is SB to BH . But as DS is to DK , so, by Construction, is SA to GA , and $S a$ to $G a$; therefore, as $SA : GA :: S a - s a$ or $Ss : aG - AG$, or $A a$. And therefore, we have $SD : DK :: SC : Ci :: SB : BH :: Ss : A a$. But this is the Property

To describe a
Planet's Or-
bit, or to find
its Position
and Eccen-
tricity.
Plate XXV.
Fig. 6.

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perty of an Ellipse whose *Focus* is S , and greater Axis Aa , as is demonstrated by the Writers of Conicks, and particularly by Mr. *Milnes*, in his *Treatise of Conick Sections*, Part IV. *Prop.* 9. It is evident therefore, that the Ellipse described with the *Foci* Ss , and Axis Aa , will pass through the Points B , C and D .

BECAUSE in *Astronomy* a Calculation is always preferable and more useful than the neatest Construction, the Form and Position of the Ellipse is in this Manner found out by Computation. In the Triangle $DS C$, having the Sides DS and CS , and the Angle $DS C$, we can find out the Side DC , with the Angles SCD and SDC ; and, in the same Manner, we can find in the Triangle BSC the Side BC , and the Angles SBC and SCB : And, because we have the *Ratio* of DF to CF , and we have DC , we shall also have CF . In like Manner, because we have the *Ratio* of CE to BE , and we have BC , we shall have CE and BE . But we have the Angle BCD , equal to the Sum of two known Angles, and therefore, we have the Angle FCE , its Complement to two Right-angles. In the Triangle FCE , we have the Sides FC and CE , and the Angle FCE ; wherefore we can find the Angle FEC , and, its Complement to a Right, the Angle iCE ; to which adding the known Angle SCB , we have the whole Angle SCi : And because Sa and Ci are parallel, the Angle CSa is equal to the Angle SCi : Having therefore the Angle CSa , we have the Position of the Axis. In the right-angled Triangle ECi , having EC and the Angle E , we can find Ci ; and therefore, we can find the Proportion of CS to Ci . In the Triangle CSL , right-angled at L , we have the Angle CSL , the Complement of the Angle CSa to two Right-angles and the Side CS : Therefore, we shall have SL , to which adding LG , equal to Ci , we have the whole SG : And because CS and Ci are known, their Proportion will be known:
As

As CS is to Ci , so let SA be to AG , and so let Sa be to aG , and so let Ss be to Aa , and we have the *Apsides* of the Ellipse A and a , and its *Foci* S and s , which were to be found. 

WE shewed above, how by an Observation to find the *heliocentrick* Place of a Planet; and we have now shewed, how to determine the Position of the *Aphelion*; by which Means, we can find the Distance of a Planet from the *Aphelion*, at the Time of the Observation; this Distance from the *Aphelion*, is called the *true* or *co-equated* Anomaly of the Planet. But having the Eccentricity of the Orbit, and the periodical Time, we shewed before, how to find the Planet's mean Anomaly, in the *Lecture* in which we gave the Solution of *Kepler's* Problem; therefore, at the Time of the Observation, we shall have the mean Anomaly of the Planet, or the Place he would have in his Orbit, did he constantly proceed with the same angular Motion round the Sun. This being once obtained, we have the Planet's mean Motion for any other Time. For say, as the periodical Time of the Planet is to the Time between the Observation and the Moment of Time for which the mean Place is desired, so is 360 Degrees, or a whole Circle, to a Fourth. This Arch, if the Time preceded the Observation, being subtracted from the Place before found, or added to it, if it comes after the Observation, will give the mean Place of the Planet for the Time proposed.

*How to find
a Planet's
mean Ano-
maly.*

FOR the more easily finding the mean Place of a Planet, for any Moment of Time, it will be easiest to take out its Motion from the *astronomical* Tables, in which is set down the Planet's mean Place or mean Anomaly, in the Beginning of any remarkable *Æra*; such as is from the Birth of our Lord, the *Æra* of *Nabonasser*, of the Creation, the Building of *Rome*, or the first Year of the *Julian* Period. The Places of the Planets, at these Instants of Time, are found by the preceding Methods, and are computed according to the *Meridian* of *equal Time*, and not for the *apparent Time*. The Place for that Time is called the *Epocha* or *Radix*, that is, the Root, *The Radix,
or Epocha.*

Lecture from which, as from an immoveable Foundation,
XXVI. all the Motions are calculated.

How to compute the mean Anomaly. IF the Times be numbred by the Years from the Birth of CHRIST, or from the Beginning of the Julian Period, it will be most convenient that the Year take its Beginning from that Mid-day which preceded the first of *January*; so that at the Mid-day of the first of *January*, there is one Day completely finished. Say, as the periodical Time is to a common Year of 365 Days, so is a whole Circle, or 360 Degrees, to a Fourth, which will be the mean Motion of the Planet for one Year. In like Manner say, as the periodical Time is to a Day, so a whole Circle is to a Fourth; and we shall have the mean Anomaly pertaining to one Day. And by working with the like Proportion, we shall have the mean Anomaly for an Hour, and for every Minute and Second. And if we add the Motion for one Year continually to itself, we shall have the Motion in two, three, and four Years: But because every fourth Year is *Bissextile*, and consists of 366 Days, to the Motion of the fourth Year we must add the Motion of one Day; then, by constantly adding the Motion of one Year, we shall have the Motion of five, six, and seven Years. But the Motion of the eighth Year is to be increased by the Motion of one Day, or rather the Motion of four Years is to be doubled, to have the Motion of eight Years; because that Year is *Bissextile*. From these Motions, so collected by Addition, we must always reject the whole Circles, or 360 Degrees; for after a Planet has completed its Circle, it returns to the same Place. By this Method we have the mean Place of the Planets to twenty Years; and if the Motion of twenty Years be constantly added to itself, we shall have the mean Place for 40, 60, 80, and 100 Years; and to each of them add the Motion of ten Years, and we have the Motions and Places for 30, 50, 70, and 90 Years. And by the continual Addition of the Motions of 100 Years, rejecting always whole Circles, we shall have the Motions of 200, 300, 400, 500, &c. Years, even to 1000: And proceeding

ceeding in the same Way, we shall have the Motion of 2000, 3000, 4000, and 5000 Years, and so as far as you will.

THESE Motions, being in this Way computed, are to be disposed in Tables, which are called Tables of the mean Motion; or mean Anomaly, when they are numbred from the *Aphelion*; and they are found in *astronomical* Tables for each Planet. But if the mean Motions are computed from the Equinoctial Points, instead of the periodical Time, you must take the Time the Planet revolves in the *Zodiac*, which is somewhat less than the periodical Time, because of the Precession of the Equinocties, by which the Intersection of those Points meet the Planet. If the *Aphelia* of the Planet be supposed to move, this Motion must be considered; and the Motion of the Equinocties, and of the *Aphelia*, (which, for ought we know, are equal but in the Moon) are likewise to be computed and disposed in Tables, for Years, Tens, Hundreds, and Thousands of Years, as the other mean Motions are; that for any Time, we may have the Places and Distances or the *Aphelia* from the Equinocties.

THE *Astronomers* have some other Tables which give the true Anomaly answering to every Degree of mean Anomaly, which are computed by some of the Methods delivered above in the former *Lectures*. If Minutes and Seconds are added to the mean Motions, we must take the Difference of the true Anomalies, which are one Degree distant from each other; and, by proportioning, we must add that Part which is to be added to the tabular Anomaly which is next least, or is to be subtracted from it, if it be next greatest.

FOR the Motions of the Sun and Moon, they commonly compute the Equations or *Prosthaphæresis*; which are the Differences between the true and mean Anomaly; and they, either subtracted or added to the mean Anomaly, as the Planet is in the first or second Semicircle of Anomaly, give the True.

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The Argument of Latitude.

The curtate Distance of a Planet.

HAVING the Places of the *Aphelion* and *Nodes*, we have their Distance from each other: And therefore, having the true Anomaly of the Planet, we have its Distance from the *Node*, which is called the *Argument of Latitude*, by which, and an easy *trigonometrical* Calculation, we can find the central Latitude of the Planet, and its *curtate Distance* from the Sun, which is the Distance from the Sun to that Point, where a Perpendicular, let fall from the Planet, meets with the *Ecliptick*. And thus we have shewed how to find the central Place and Latitude of the Planet, and its *curtate Distance* from the Sun. After these are found, we shall likewise be able to find his *geocentrick* Place, or where he will be seen from the Earth, in the following Method.

PL. XXVII. Fig. 1. FIND first the Planet's *heliocentrick* Place, and *curtate Distance* from the Sun; as also the Earth's Place and Distance from the same. Let T C F be the Orbit of the Earth, in which the Earth is in T; A P E the Orbit of the Planet, and its Place P, the Sun S, *n* S N the Line of *Nodes*. From the Place of the Planet let fall, on the Plane of the *Ecliptick*, the right Line P B; draw S B, and produce it till it meet with the *Ecliptick* in the Planet's Place reduced to the *Ecliptick*; which Place is found by the Arch P N, and the Inclination of the Orbit to the Plane of the *Ecliptick*, which are known: But we have the Place of the Earth seen from the Sun; and therefore we have the Distance between them, or the Angle T S B, which is called *the Angle of Commutation*. Then, in the Triangle S T B, we have S T, the Distance of the Earth from the Sun, and S B, the *curtate Distance* of the Planet; wherefore, we shall find the Angle S T B, the Elongation of the Planet from the Sun, or the Arch of the *Ecliptick* intercepted between the Sun's Place and the Planet's Place, reduced to the *Ecliptick*; as also T B, the *curtate Distance* of the Planet from the Earth. But the Place of the Sun is given, for it is opposite to the Place of the Earth seen from the Sun: Wherefore, also we shall have the Place of the Planet in the *Ecliptick*, as it is seen from the Earth. Moreover,

How to compute the Planet's geocentrick Place.

over, in the two Triangles PSB and TPB, that are rectangular at B, the Tangent of the Angle PSB is to the Tangent of the Angle PTB, as TB is to SB: But as TB is to SB, so is the Sine of TSB, the Sine of the Commutation, to the Sine of the Elongation STB. Wherefore say, as the Sine of the Commutation is to the Sine of the Elongation, so is the Tangent of the heliocentrick Latitude to the Tangent of the geocentrick Latitude, which was to be found. And by these Means the *Astronomers* are able to find, for any Instant of Time, the geocentrick Place and Latitude of any Planet.

COMPARING the Distances of the Planets from the Sun, with the Times of the Periods round him, we find that they all observe a wonderful, regular, and elegant Harmony and Law, viz.

THE *Squares of the periodical Times are in all of them proportional to the Cubes of their mean Distances from the Sun.* Now their Periods and mean Distances are these, which we here give in the following Table.

| | The Periods. | | | | Mean Distances. |
|---|--------------|----|----|----|-----------------|
| | D. | h. | ' | " | |
| ♂ | 10759 | 6 | 36 | 26 | 953800 |
| ♂ | 4332 | 12 | 20 | 35 | 520110 |
| ♂ | 686 | 23 | 27 | 30 | 152369 |
| ☉ | 365 | 6 | 9 | 30 | 100000 |
| ♀ | 224 | 16 | 49 | 24 | 72333 |
| ♀ | 87 | 23 | 15 | 53 | 38710 |

THE illustrious Mathematician Mr. *Hugens*, has determined very nicely the Diameters of the Planets, by comparing them with that of the Sun, in his *Saturnian System*, which he did by the following Method.

COPERNICUS, by his new and divinely invented System, has shewed us how to find out the Distance of each Planet from the Sun, in proportion to the Earth's Distance from the same: But their apparent Diameters, and how much some are bigger than others, has been discovered by the Help of the Te-

Lecture XXVI. telescope. For by comparing the Proportions of their Distances and apparent Magnitudes, the Proportion of their true Bigness to that of the Sun will easily be found, by the Principles we have laid down in our first *Lecture*.

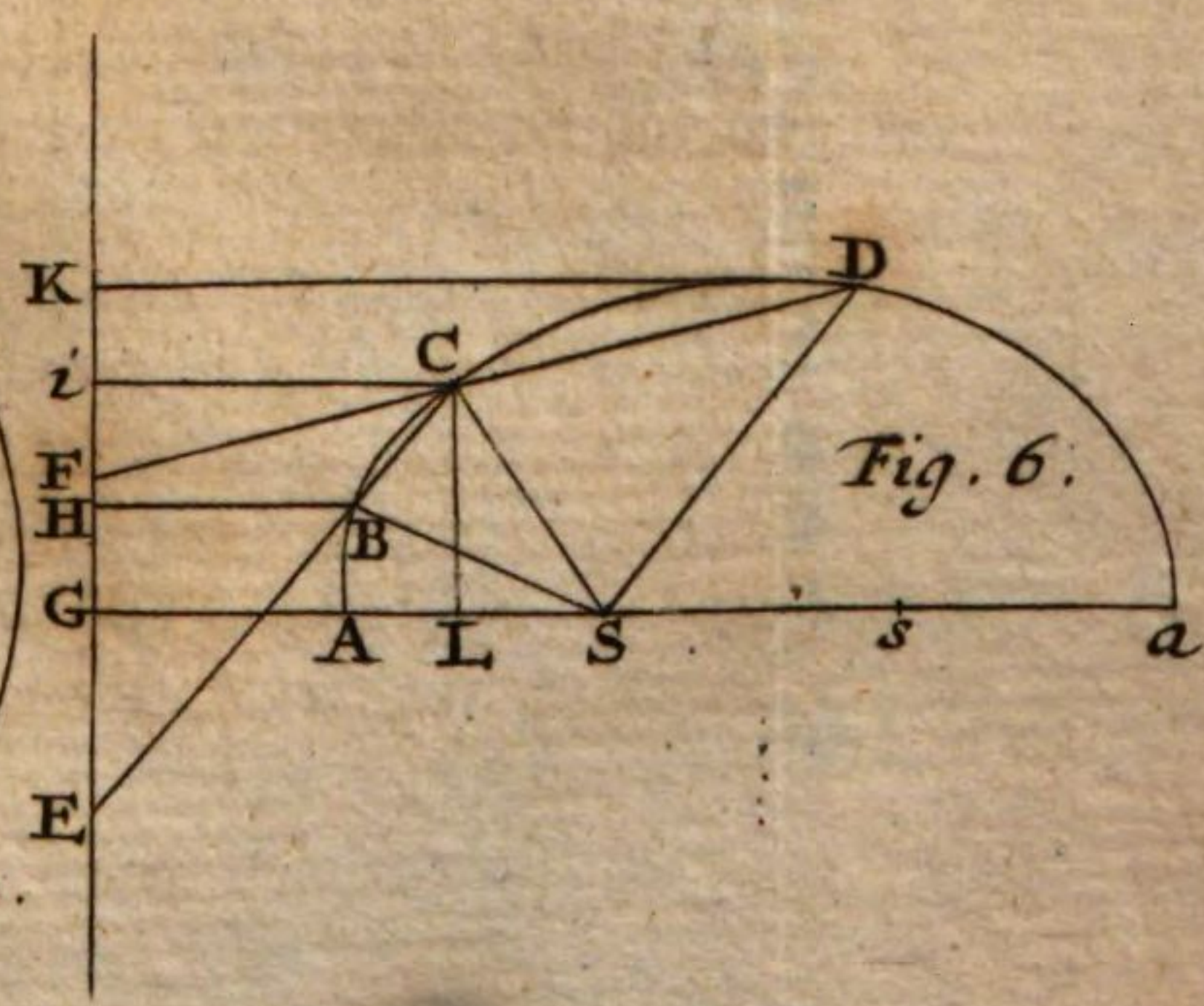
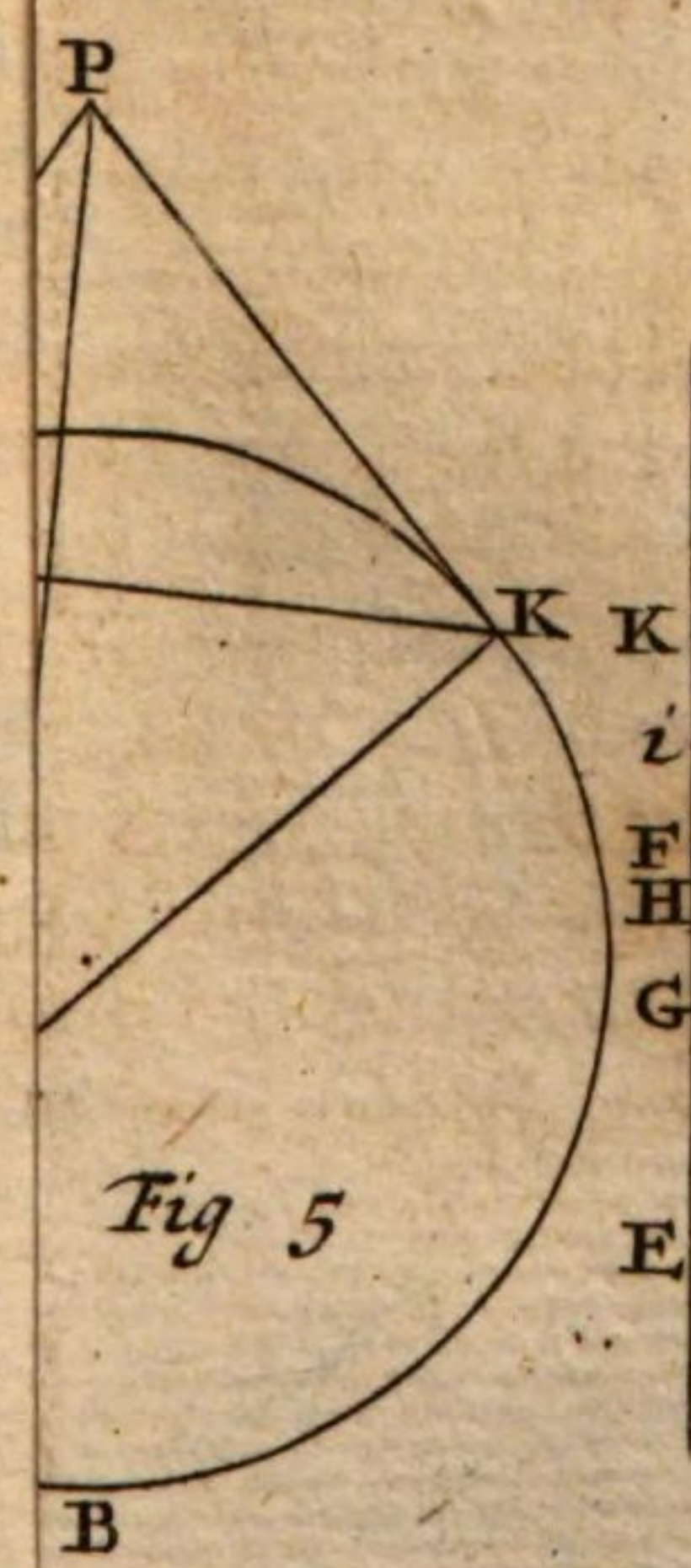
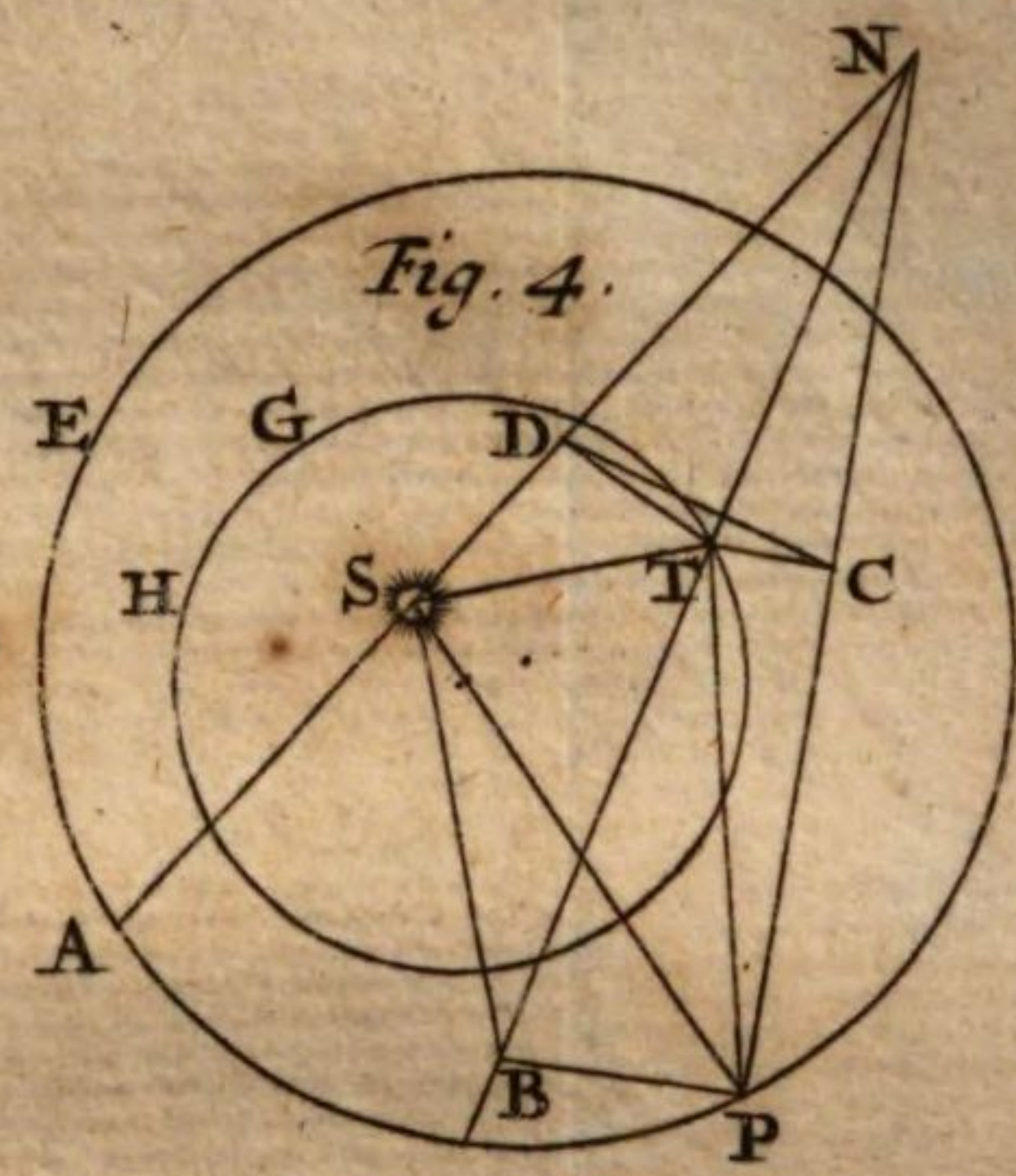
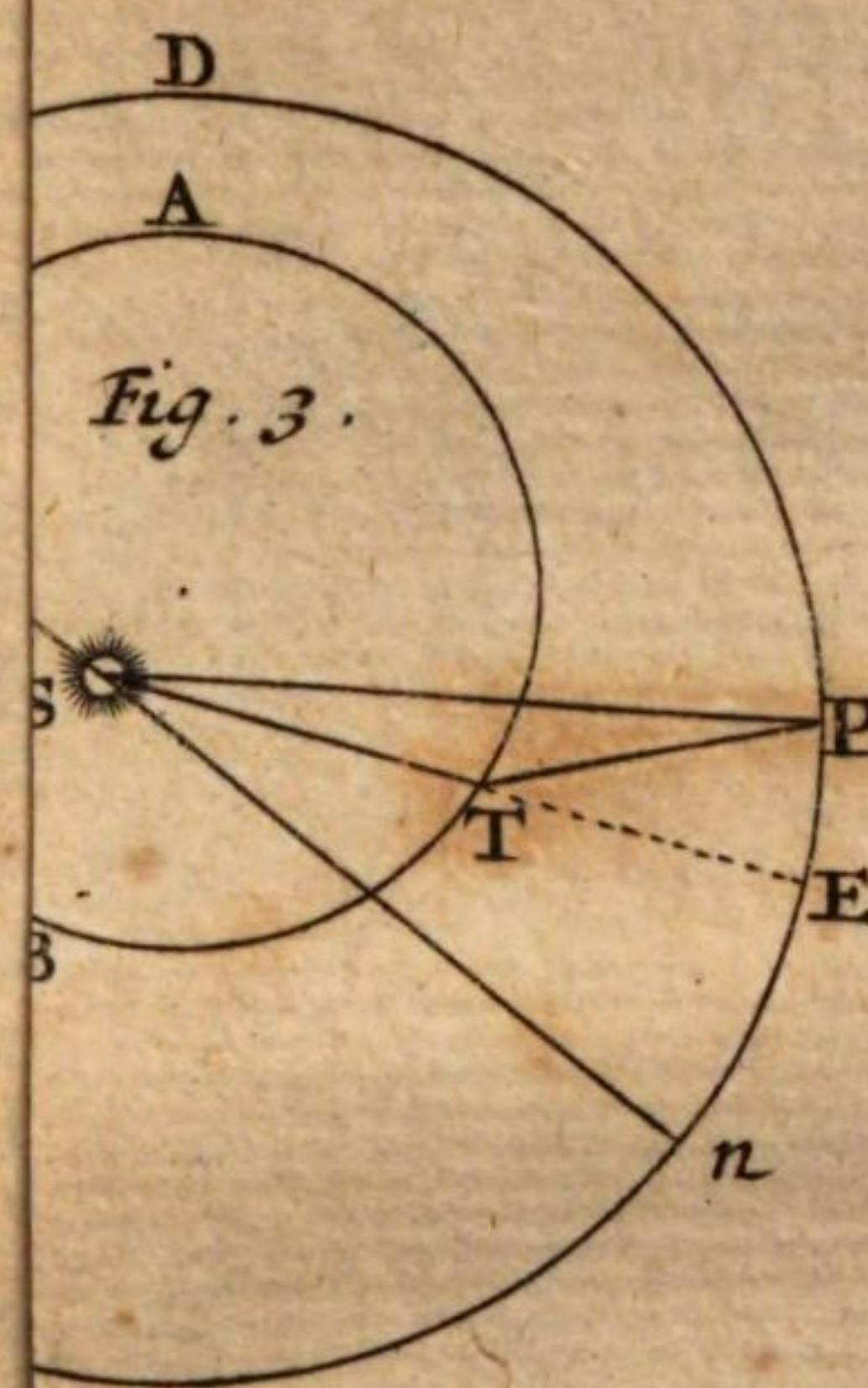
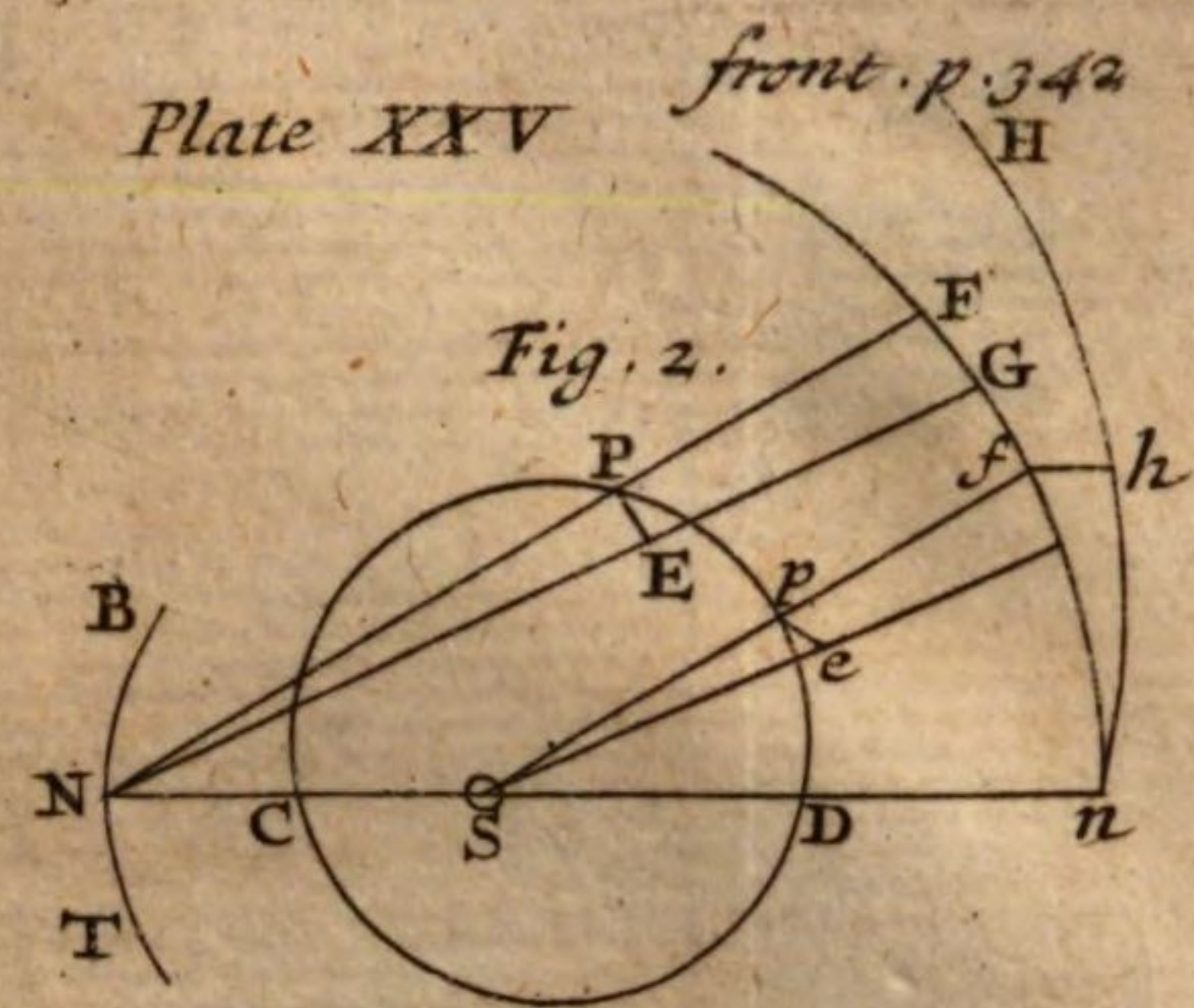
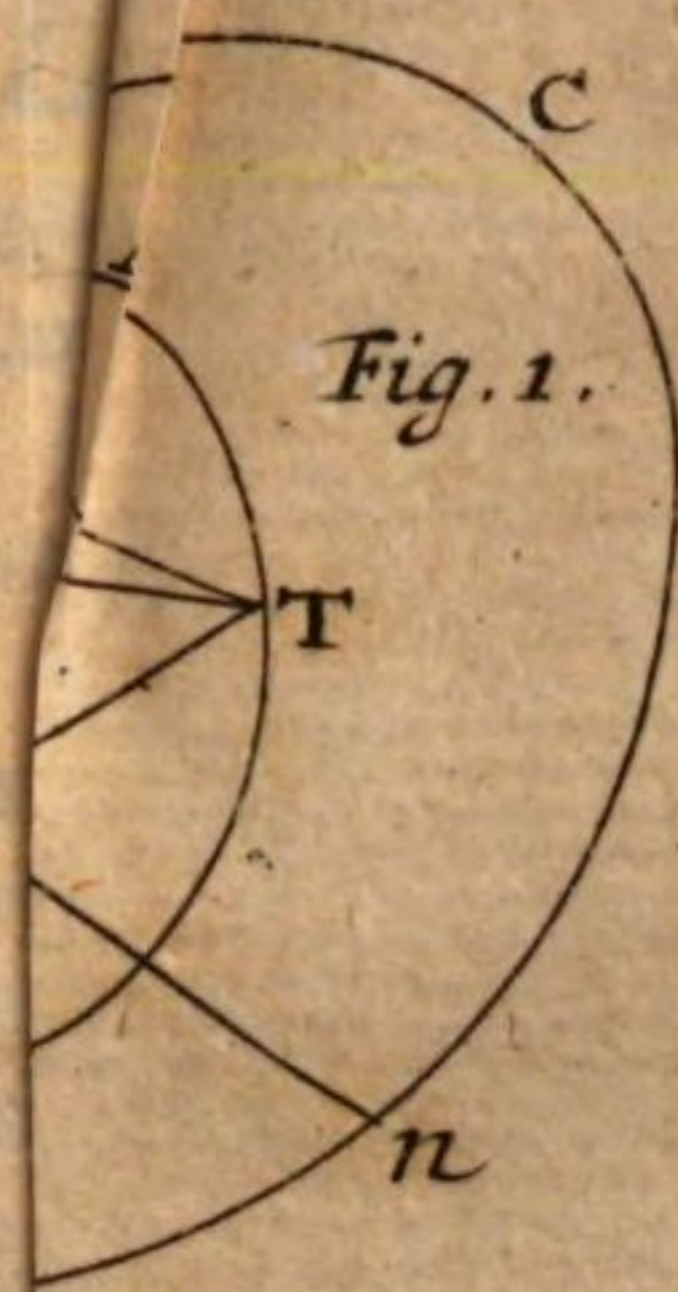
The Diameters and Magnitudes of the Planets estimated.

As for *Saturn*, the Diameter of his Ring, when he is nearest to us, subtends an Angle of 68 Seconds. And, because this least Distance of *Saturn* is near eight Times the mean Distance of the Sun from us, it follows, that if *Saturn* were as near us as the Sun is, the Diameter of the Ring would appear eight times bigger than now it does, that is, it would be $9' 4''$. But the Diameter of the Sun in his mean Distance is $30' 30''$. Therefore, the Proportion of the Diameter of the Ring to the Diameter of the Sun, is that of $9' 4''$ to $30' 30''$; which is near the Proportion of 11 to 37. But the Diameter of *Saturn's* Body is to the Diameter of the Ring, as 4 to 9; that is, nearly as 5 to 11: And therefore, it is to the Diameter of the Sun, as 5 to 37.

JUPITER's Diameter, when he is next to us, is 64 Seconds; and then his Distance is to the mean Distance of the Sun, as 26 to 5; say, as 5 is to 26, so is 64 Seconds to a Fourth; which will be $5' 35''$: which is the Bigness of the Angle that *Jupiter's* Diameter would subtend, were he as near as the Sun is: But the Sun is seen under an Angle of $30' 30''$; therefore the Proportion of *Jupiter's* Diameter to that of the Sun, is, as $5' 35''$ to $30' 30''$; that is, a little more than 1 to $5\frac{1}{2}$.

VENUS, when she is nearest the Earth, subtends an Angle of 85 Seconds; and then her *Perigæon* Distance is to the mean Distance of the Sun nearly, as 21 is to 82: And therefore, if *Venus* were removed to the Distance of the Sun, her Diameter would be only $21'' 46'''$: And therefore we know, that the Diameter of *Venus* is to that of the Sun, as $21'' 46'''$ to $30\frac{1}{2}'$; that is as 1 to 84.

BUT the Diameter of *Mars*, when nearest to the *Earth*, is not greater than $30''$: And therefore, since the least Distance of *Mars* is to the Sun's mean Distance, as 15 to 41; the Proportion of *Mars's* Diameter



ameter will be to the Sun's Diameter, as 1 is to 166: Therefore *Mars* is but half the Bigness of *Venus* in its Diameter. *Hevelius*, by Observations, found, that *Mercury's* Diameter was to that of the Sun, as 1 is to 290.

THE Magnitude of the Earth, in Comparison of that of the Sun, is variously estimated by the *Astronomers*: They who suppose the horizontal Parallax of the Sun to be 15 Seconds, must make the Distance of the Sun from us, to be but 13750 Semidiameters of the Earth; and the Diameter of the Earth will be to the Diameter of the Sun, as 1 to 61: But we have a probable Argument, which proves the Disproportion or Inequality greater. For, because the Diameter of the Moon is somewhat more than a fourth Part of the Diameter of the Earth, if the Parallax of the Sun were 15 Seconds, then the Body of the Moon would be greater than that of *Mercury*; but it seems incongruous that a secondary Planet should be greater than a primary Planet. Let us suppose therefore, that the Semidiameter of the Earth, seen from the Sun, be 11 Seconds, as it was lately collected from the Parallax of *Mars*, observed by Dr. *Halley* and Mr. *Pound*: And then the Earth's Distance will be nearly 20000 Semidiameters of the Earth, and the Moon will be less than *Mercury*. And the Proportion of the Diameter of the Earth to the Sun will be that of 1 to 83; to which Proportion we may give our Assent, till by an Observation of *Venus* in the Sun's Body, which will happen in 1761, we may be made more certain of the Sun's Parallax. Therefore, the Diameter of the Sun is to the Planets Diameters, nearly in the Proportions represented in the following Table.

| | | | | |
|--|---|-----------|---|------------------|
| The Diameter of the Sun
is to the Diameter of | { | Saturn | { | 137 |
| | | Jupiter | | 181 |
| | | Mars | | 6 |
| | | the Earth | | 12 |
| | | Venus | | 12 |
| | | Mercury | | 4 |
| | | | | as 1000
is to |
| Z 4 | | | | AND |

Lecture
XXVI.AND because Spheres are to one another, as the
Cubes of their Diameters.

| | | | | | |
|-----------------------|---|------------------|-------------------------|---|---------|
| The Sun
will be to | { | <i>Saturn</i> | as 10000000000
is to | { | 2571353 |
| | | <i>Jupiter</i> | | | 5929741 |
| | | <i>Mars</i> | | | 216 |
| | | the <i>Earth</i> | | | 1728 |
| | | <i>Venus</i> | | | 1728 |
| | | <i>Mercury</i> | | | 64 |

HENCE it follows, that the Sun is a hundred and sixteen Times bigger than all the Planets put together. *Saturn* is 400 Times less than the Sun: But for Quantity of Matter it is 2400 Times less than the Matter of the Sun, *Jupiter*, the biggest of all the Planets, is 160 Times less than the Sun, and his Matter, that composes his Body, is 1033 Times less than the Matter of the Sun. But our Earth, if it be compared with the Sun, is but of a very small Magnitude, and not bigger than a physical Point; for it is 500000 Times less than it. Besides, comparing the Planets with one another, we find, that *Jupiter* is bigger than all the rest of the Planets put together; and that he is above 3000 Times bigger than the Earth; but *Venus* is of the same Bigness with the Earth. And yet there are two of the six Planets, viz. *Mercury* and *Mars* less than the Earth,



LECTURE



LECTURE XXVII.

Of the Stations of the Planets.

IF the Earth were at Rest, and the Planets alone turned round the Sun, an inferior Planet would seem to be stationary, in that Point of its Orbit, where a Line drawn from the Earth touched the Orbit; for when the Planet is near that Point, if the Earth stood still, it would directly approach the Earth, and would have no visible Motion, or at least, its visible Motion would be the least of all. In like manner, if a superior Planet were at rest, when it is viewed from the Earth, it would appear to stand in that Part of its Orbit, where a Line drawn from the Planet touches the Earth's Orbit. But because both the Earth and Planets move round the Sun, when an inferior Planet, is in the fore-mentioned Tangent, then the Motion of the Earth, will make the Planet appear to change its Place, and the Planet will not be come to its apparent Station. And, upon the same Account, when the Earth is in the Line which touches its Orbit, and passes to a Planet, the proper Motion of the superior Planet, will change its visible Place. And therefore it happens, that neither an inferior Planet seems to rest, when it and the Earth are in a Line which touches its Orbit; nor is a superior Planet stationary, when the Earth and it, are in a Line touching the Orbit of the Earth.

An inferior Planet is not stationary, when it is seen in a right Line touching its Orbit.

Nor is a superior stationary when it is seen in a Line touching the Earth's Orbit.

BUT

Lecture
XXVII.

When a Planet appears stationary.

BUT since all the Planets do sometimes appear to move forward, and afterwards to return backwards; between the progressive Motion and the regressive, there will be some Point, where it will appear to stand and continue in the same Situation in the Heavens. Now it seems to keep the same Station in the Heavens, when the Line that joins the Earth and Planet's Center is constantly directed to the same Point in the Heavens; that is, when it keeps parallel to itself: For all right Lines, drawn from whatever Point of the Earth's Orbit, parallel to one another, do all point to the same Star; because the Distance of these Lines is not sensible in Comparison of the great Distance of the fixed Stars.

THEREFORE, to find out the Points of Station, we must inquire the Position of the Line, which, joyning the Earth and Planet, keeps parallel to itself: For which Purpose we must observe, that if the Centers of the Sun, Earth and Planet be joined by right Lines, they will form a Triangle, whose two Sides drawn from the Sun, are always equal to the Distances of the Earth and Planet from the Sun; and the Base is a right Line joining the Earth and Planet: And because the Sides of this Triangle, in circular concentrick Orbits, do keep always the same Magnitude, the Proportion of the Sines of the Angles at the Base, will be constantly the same: For the Sines are as the opposite Sides.

Table XVI.
Fig. 1.

LET the Circle BDG, be the Orbit of the Planet, and AHK, the Orbit of the Earth concentrical to it. And let us suppose the Earth in A, the Planet in B, and the Sun in the Center S. In the Triangle ASB, the Sines of the Angles A and B, at the Base, are as the opposite Sides SB, SA.

LET us suppose then, that in a small Particle of Time, the Earth is moved through the small Arch AC, and the Planet at the same Time through the Arch of its Orbit BD; their angular
Motions

Motions at the Sun, made in the same or equal Times, are reciprocally as their periodical Times; for how much the greater is the periodical Time, so much less is the Angle it describes, round the Sun in any given Time. Therefore, the Angle ASC , the angular Motion of the Earth, is to the Angle BSD , the angular Motion of the Planet, as the periodical Time of the Planet is to the periodical Time of the Earth; that is, the angular Motions in the same Time are in a constant Proportion.

LET the Center of the Earth in C , and of the Planet in D , be joined by the Line CD , which is parallel to the former Line AB : And in that Case, as we have shewed, the Planet will appear stationary. Let SA cut CD in M , and SD , produced, cut AB in E : And because AB and CD are parallel, by the 29th of *El. I.* the Angle SMD will be equal to the Angle A ; but by the 32d of the first *El.* the Angle SMD is equal to the Angles C and MSC ; wherefore the Angle C is equal to the Angle A , bating the Angle MSC or CSA . Likewise, because of the Parallels AB and CD , the Angle SDC is equal to the Angle SEA , which is equal to the Angles SBA and BSE ; wherefore that Angle is equal to the Sum of the two Angles SBA and BSE . Therefore the momentaneous Increase of the Angle SBA is equal to the angular Motion of the Planet at the Sun. And before it was shewed, that the Decrement of the Angle A , was equal to the Angle ASC , or to the angular Motion of the Earth; but these angular Motions are constantly in a given Proportion, which is reciprocal to their periodical Times.

A Planet therefore appears stationary when the momentaneous Change of the Angle at the Earth is to the momentaneous Change of the Angle at the Planet, as the periodical Time of the Planet is to the periodical Time of the Earth.

LET there be two Arches or Angles, whose Sines are to one another in a constant Proportion.

Table XVI.
Fig. 2.

Lecture XXVII. tion. I say, that their Co-sines, or the Sines of the Complements of these Arches, are in a Proportion compounded of the direct Proportion of the Sines of these Arches, and a reciprocal Proportion of the momentaneous Changes of the Arches or Angles. For Example, Suppose the two Arches AM and CM , whose Sines are AB and CD , and their Co-sines SB , SD . Let the Arches AM and CM decrease into EM and GM ; so that the Sines EK , GL , may be proportional to the former AB and CD . Let AE and CG be the Decrements of the Arches, which being infinitely small, may be taken for Right-lines. Draw FE and GH , parallel to SM ; the Triangles AFE and ASB are equiangular: For the Angles B , and AFE are both right, and the Angle EAF is equal to the Angle ASB , the Angle SAB being the Complement of both to a Right Angle. After the same Way it may be proved, that the Triangles CHG and $CS D$ are equiangular. Therefore $CG:CH::CS:SD$; and $AF:AE::SB:AS$ or CS : Wherefore multiplying the Antecedents together, and the Consequents together, we have the Proportion $CG \times AF:CH \times AE::CS \times SB:SD \times AS$ or $CS \times SD::$ that is, SB is to SD in a Proportion compounded of AF to CH and of CG to AE . But the *Ratio* of AF to CH , is the same with the *Ratio* of the Sines AB and CD ; and the *Ratio* of CG to AE is the *Ratio* of the momentaneous Decrements of the Arches CM and AM . Therefore SB , the Co-sine of the Arch AM , is to SD , the Co-sine of the Arch CM , in a Proportion, compounded of the direct Proportion of the Sines of these Arches, and a reciprocal Proportion, of the instantaneous Decrements of the Arches, that is of CG to AE .

HENCE, if the Centers of the Sun, of the Earth, and of a Planet that is stationary, be joined with Lines, the Co-sine of the Angle at the Earth, will be to the Co-sine of the Angle at the Planet in a Proportion, composed of the Sines of the

the Angles A and B, and a reciprocal Proportion of the momentary Decrease of those Angles A and B. But the Proportion of the Sines is the same with the Proportion of the Distances of the Earth and Planet from the Sun; and the *Ratio* of the momentary Decrease of the Angles A and B is the Proportion of the periodical Times of the Planet and the Earth, as has been proved. Let the periodical Times be called t and T ; and then the Co-sine of the Angle A will be to the Co-sine of the Angle B, when the Planet is stationary, as $T \times SB$ is to $t \times SA$; that is, the Co-sine of the Angle at the Earth is to the Co-sine of the Angle at the Planet, in a Proportion, compounded of the periodical Times directly, and a reciprocal Proportion of the Distances from the Sun. Hence the Points of Stations are easily determined by the following Construction.

LET AH be a Portion of the Orbit of the Earth, G B K a Portion of the Planet's Orbit, and let the Sun S be in the Center of both Orbits. Cut SA in E, so that SA may be to SE, as the periodical Time of the Earth is to the periodical Time of the Planet. Upon the Diameter AE, describe a Semicircle cutting the Orb of the Planet in B, the Angle SAB will be the Elongation of the Planet from the Sun, when it appears stationary. Draw the Lines ABF, EB, and SF, parallel to EB, and the Angle ABE in a Semicircle, is a Right-angle: And therefore, AFS parallel to it, must be right likewise. Moreover, $AS : AF :: \text{Rad.} : \text{Co-sine of } A$; and also, $BF : SB :: \text{Co-sine } SBF : \text{Rad.}$ Therefore multiplying the Antecedents together, and the Consequents together, we shall have $AS \times BF$ to $AF \times SB$, as the Co-sine of SBF is to the Co-sine of the Angle A. Therefore, the *Ratio* of the Co-sine of the Angle A, to the Co-sine of the Angle SBF, is compounded of the *Ratio* of AF to BF, and of SB to AS. But the *Ratio* of AF to BF is equal to the *Ratio* of AS to SE,
or

Lecture or of T to t . Therefore, the *Ratio* of the Co-sine
 XXVII. of the Angle A , to the Co-sine of the Angle SBF ,
 is compounded of the *Ratio* of T to t , and of SB
 to SA . But it was shewed, that when the Co-sines
 of the Angles had this Proportion, then the Planet
 should be stationary. Therefore it is evident, that
 when the Planet is in B , and the Earth at A , the
 Planet will appear to be stationary.

HENCE we see, that when an inferior Planet
 is seen from the Earth to be stationary,
 the Earth also, viewed from the inferior, will
 likewise appear to be stationary, and will seem
 to remain in the same Place. For the Earth is
 seen stationary, when the Line that joins the Cen-
 ters of the Planet and Earth keeps parallel to it-
 self; and so long as this Line keeps a Parallelism,
 it will always be directed to the same Point in the
 Heavens.

By the same Method, we find the Positions of
 the other superior Planets, in respect of the Earth
 and Sun, when they are to be observed by us to
 be stationary, *viz.* by inquiring where the Earth,
 considered as an inferior Planet, will appear station-
 ary, seen from a superior Planet.

IF the periodical Times were proportional to
 the Distances from the Sun, the Points E and B
 would coincide with G , and the Planet would be
 stationary, when the Angle A was nothing; that is,
 when the inferior Planet was in Conjunction with
 the Sun: But if SE bore a greater Proportion to
 SA than SG did to SA , the Circle ABE could
 cut the Planet's Orb in no Point at all; and the
 Planet could no where be stationary, but would
 appear constantly to move directly forward: But
 neither of these Cases obtain Place in the Planets;
 for SE is always less than SG or SB , which I
 thus demonstrate.

CALL the Distance of the Earth from the
 Sun p , the Distance of the Planet SG or SB
 call q , the periodical Times T and t . And, by
 the universal Law above explained and obser-
 ved

ved in all the Planets, we have $T^2 : t^2 :: p^3 : q^3$, Lecture
 and $T : t :: p^{\frac{3}{2}} : q^{\frac{3}{2}} :: p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}}$; but as T XXVII.
 is to t , so is SA : SE :: $p : SE$. Say there-

fore, as $p \times p^{\frac{1}{2}} : q \times q^{\frac{1}{2}} :: p$ to $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$; which

is therefore equal to SE: And because p
 is greater than q ; therefore, $q \times p^{\frac{1}{2}}$ is greater
 than $q \times q^{\frac{1}{2}}$; and dividing all by $p^{\frac{1}{2}}$, we have
 q greater than $\frac{q \times q^{\frac{1}{2}}}{p^{\frac{1}{2}}}$ or than SE. And there-

fore, since SB or SG is greater than SE, the
 Circle upon the Diameter AE, will cut the Orbit
 of the Planet: And therefore, we, on the Earth,
 in some certain Positions, may see each of the Pla-
 nets stationary.

IF you desire to use a Calculation, the An-
 gle at the Earth, or the Elongation of the Pla-
 net from the Sun, is defined in this Manner. Let
 the Radius be z , and the Sine of the Angle at
 the Earth $q x$; the Sine of the Angle at the Pla-
 net, will be $p x$, supposing that p is to q in the
 Proportion of the Earth and Planet's Distances from
 the Sun: And because the Sine of the Angle at
 the Earth is $q x$, its Co-sine is $\sqrt{z^2 - q^2 x^2}$; and the
 Co-sine of the Ang. at the Planet will be $\sqrt{z^2 - p^2 x^2}$:

And therefore $\sqrt{z^2 - q^2 x^2} : \sqrt{z^2 - p^2 x^2} :: T \times q$
 $: t \times p$: And squaring the Terms of the Ana-
 logy $z^2 - q^2 x^2 : z^2 - p^2 x^2 :: T^2 \times q^2 : t^2 \times p^2$;
 but $T^2 : t^2 :: p^3 : q^3$: Wherefore, instead of T^2
 and t^2 , put p^3 and q^3 , which are proportional to
 them, and we shall have $z^2 - q^2 x^2 : z^2 - p^2 x^2 ::$
 $p^3 \times q^2 : q^3 \times p^2 :: p : q$: And therefore, we have
 the Equation $q z^2 - q^3 x^2 = p z^2 - p^3 x^2$, and

$p^3 x^2 - q^3 x^2 = z^2 \times p - q$; and $x = z \times \frac{\sqrt{p - q}}{\sqrt{p^3 - q^3}}$
 and

Lecture XXVII. and $q \times$, the Sine of the Angle at the Earth, =

$$qz \times \frac{\sqrt{p-q}}{\sqrt{p^3-q^3}}, \text{ which is equal to } \frac{qz}{\sqrt{p^2+pq+q^2}};$$

therefore the Square of the Co-sine of this Angle is $z^2 - \frac{q^2 z^2}{p^2+pq+q^2} = \frac{z^2 p^2 + z^2 p q}{p^2+pq+q^2}$; and

therefore the Co-sine is $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$: The

Co-sine is therefore to the Sine, as $z \times \frac{\sqrt{p^2+pq}}{\sqrt{p^2+pq+q^2}}$

to $\frac{qz}{\sqrt{p^2+pq+q^2}}$ as $\sqrt{p^2+pq}$ is to q . But, as the Co-sine is to the Sine, so is the Radius to the Tangent; therefore say, as $\sqrt{p^2+pq}$ is to q ,

so z is to $\frac{zq}{\sqrt{p^2+pq}}$, which is the Tangent of the

Angle at the Earth: And by this Analogy the Angle is easily found. For if half the Sum of the Logarithms of p and $p+q$ be subtracted from the Logarithm of q , there will remain the logarithmick Tangent of the Angle at the Earth. From this Value of the Tangent we have the following geometrical Construction, which determines the Angle. Let HAQ be a Portion of the Earth's Orbit, GBD the Orbit of the inferior Planet, and the Sun in S the common Center of the Orbits. Produce AS , 'till it meets with the inferior Orbit in D ; upon the Diameter AD , describe the Semicircle ACD , and at S , erect upon AD the Perpendicular SC , cutting the Semicircle in C ; join AC , in which take $AF=SD$; and from F upon AS , let fall the Perpendicular FE ; in SC take $SL=AE$, and draw AL : Then SAL will be the Angle required; and B , where AL cuts the inferior Orbit, will be the Point of the Station: For the Square of

Table XVI.
Fig. 4.

of SC is equal to the Rectangle ASD = $p q$, and AC square = AS square + SC square = $p^2 + p q$: But AC : AF :: AS : AE :: AS : SL :: The Radius: Tangent of the Angle SAL,

that is $\sqrt{p^2 + p q} : q :: z : \frac{z q}{\sqrt{p^2 + p q}}$, which is therefore the Tangent of the Angle required.

THESE Calculations and Constructions would sufficiently determine the Points of Station, if the Planets Orbits were concentric Circles: But since they are eccentric and Ellipses, both the Angles at the Sun and Planet will be different and changeable, according to the different Places of the Planets in their Orbits, at the Points of Station. And therefore because in this Case, according to the infinite Varieties of Position of the Earth and Planets in their Orbits, there will be likewise an infinite Variety of Angles, they cannot be defined by any algebraical Equation; neither can the *Problem* be universally constructed by any algebraick Curve of any Kind, although some Mathematicians have undertaken to do it. Yet, if we have the Position of a Planet in its proper Orbit, we may find the Position of the Earth in its Orbit, from whence the Planet in that Point will appear stationary.

FOR this is a determined *Problem*, and admits of two Answers, for the two Roots of the Equation that involves the Nature of the *Problem*. The most industrious Dr. *Halley*, hath communicated to me the following Solution of this *Problem*; for the understanding of which, we give the following *Lemma*.

WHATEVER the Form of the Earth and Planets Orbits may be, if from their Places in the Times of Station there be drawn Tangents to the Orbits, and produced till they meet, the Portions of those Tangents, intercepted by their mutual Concourse, are proportional to the absolute Velocities of the Earth and Planets.

LET FG and AH be two Portions of the Orbits which the Earth and Planet describe; AB and CD two infinitely small Portions of them, described

Lecture in the same Time, when the Planet is stationary:
 XXVII. Draw the Lines CE and AE touching the Orbits,
 and meeting in E. And, because the Planet is sta-
 Ta. XXVI. tionary, BD and AC will be parallel: And there-
 Fig. 5. fore, by the 2d Prop. El. VI. $CD : AB :: CE : AE$.
 But CD and AB, since they are Portions of the
 Orbits described in the same Time, are as the Velo-
 cities of the Earth and Planet: Therefore the Tan-
 gents CE and AE are as the Velocities. This
Theorem is Mr. *John Bernoulli's*, and is published in
 the *Berline Acts*, and flows immediately from the
 Parallelism of the Lines AC, BD: But Mr. *Ber-*
noulli has not given us from thence any Solution of
 the Problem. Dr. *Halley's* Solution is this.

P R O B L E M.

*To find the Place of the Earth, from
 which a Planet, seen in a given
 Point of its Orbit, would appear
 stationary.*

Ta. XXVI. SUPPOSE the Sun at S, $\Pi K L A$ the Orbit of
 Fig. 6. the Earth, which we may here suppose to be
 circular, $\pi P a$ the Orbit of the Planet, P its given
 Place. Draw VPQ, touching the Orbit in P, and
 intersecting the Orbit of the Earth in V and Q;
 bisect VQ in R, and on it erect the Perpendicular
 PB, which may be to VR or RQ, as the Velo-
 city of the Planet is to the Velocity of the Earth:
 At the Center R, upon the Diameter VQ, describe
 the Semicircle $V b d Q$, to which draw the Tan-
 gents Bb, Bd, and produce them till they meet
 with VQ produced in Σ and T; draw Rb, Rd;
 take ΣK equal $b\Sigma$, and TL equal to dT. Then
 I say, the Points K and L, are what are to be found.
 For

For, because of the equiangular Triangles $Rb\Sigma$ and $BP\Sigma$, $\Sigma P : PB :: \Sigma K : Rb$ or RV , and by alternation of Proportion, $\Sigma P : \Sigma K :: PB : RV$; but by Construction, PB is to RV , as the Velocity of the Planet is to the Velocity of the Earth; and Σb touches the Semicircle in b ; wherefore its Square is equal to the Rectangle $V\Sigma Q$, by *Prop. 36 Elem. III.* And ΣK is equal to Σb ; therefore ΣK will touch the Orbit of the Earth in the Point K , by *37 Prop. Elem. III*; therefore the Tangents of both Orbits ΣP and ΣK are as the Velocities; and therefore a Planet in P will appear stationary, when the Earth is in K . In the same Manner it may be shewed, that the right Lines PT and LT are, as the Velocities, and that LT touches the Orbit of the Earth in L . Lastly, the Lines SK SL being drawn will shew the Places of the Earth seen from the Sun, and the Angles KSP LSP are the Comutations. And if the Line SA be the Line of the *Apsides* of the Earth's Orbit, KSA and LSA , will be the Angles of the true Anomaly; and consequently, if any Error be committed in supposing the Earth's Velocity, it can be most accurately corrected, by having the true Anomaly.

It is a *Problem* of a very different Kind, to define the Time when a Planet is to be stationary; and its Solution cannot be had from common *Geometry*: yet the aforesaid Dr. *Halley*, by an indirect Method, and an Approximation, has shewed how to find it. It is as follows:

WHEN the Time of a Station is to be accurately determined.

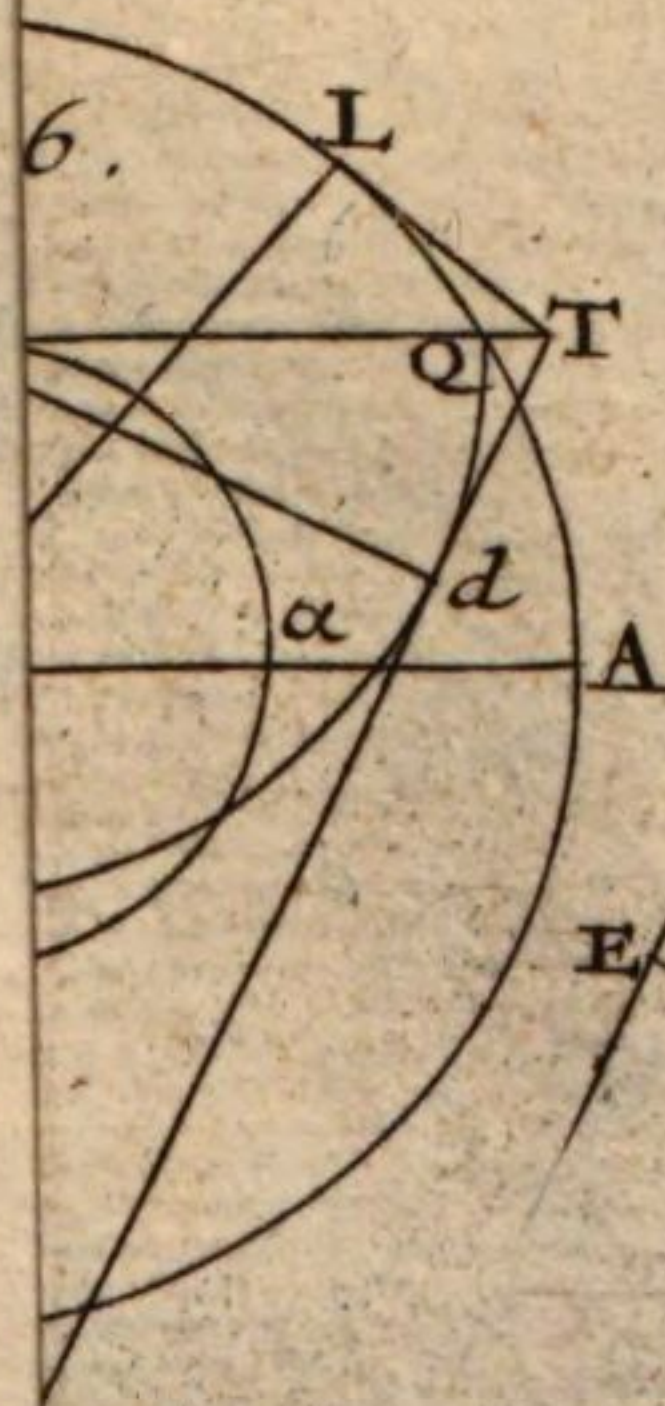
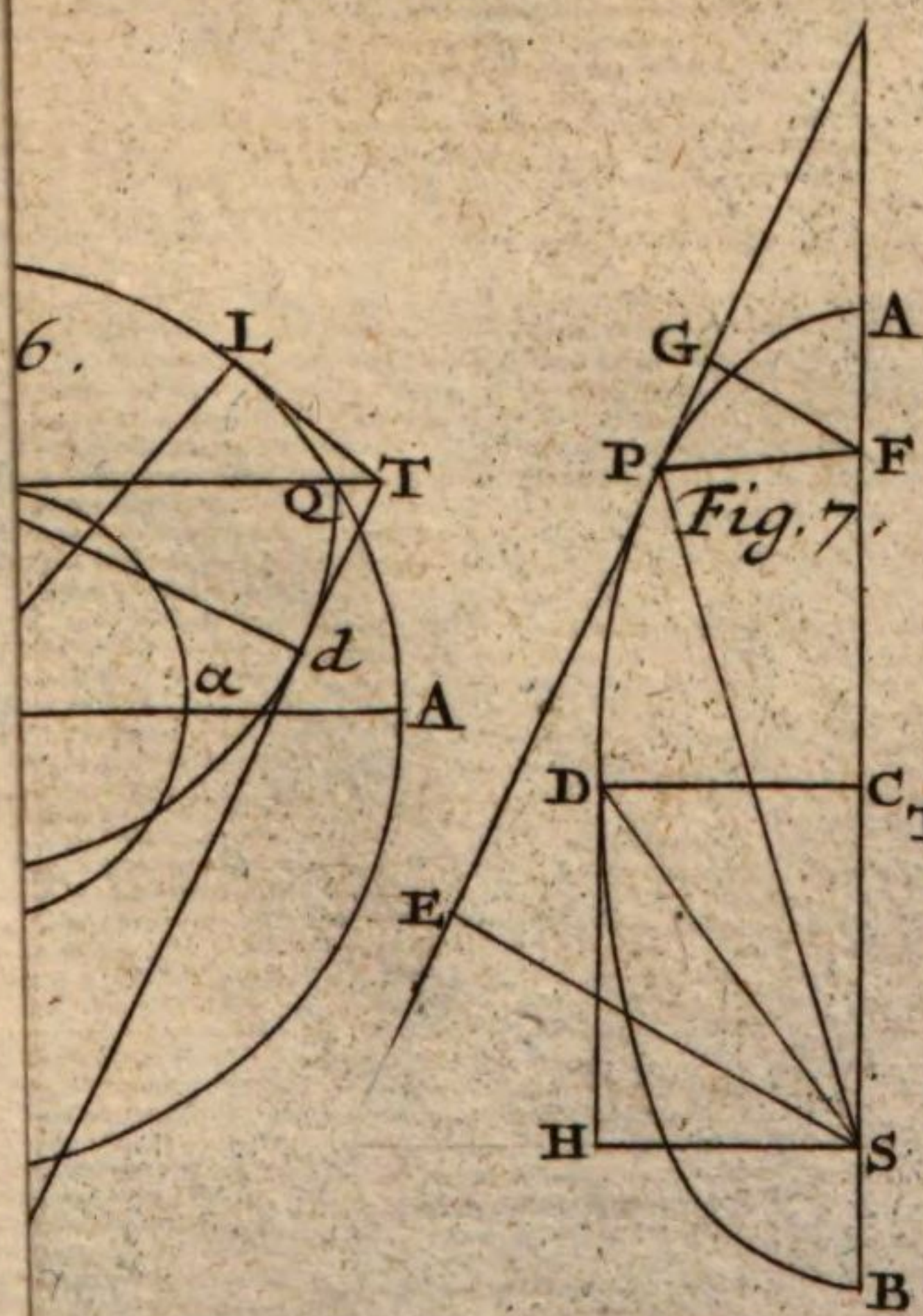
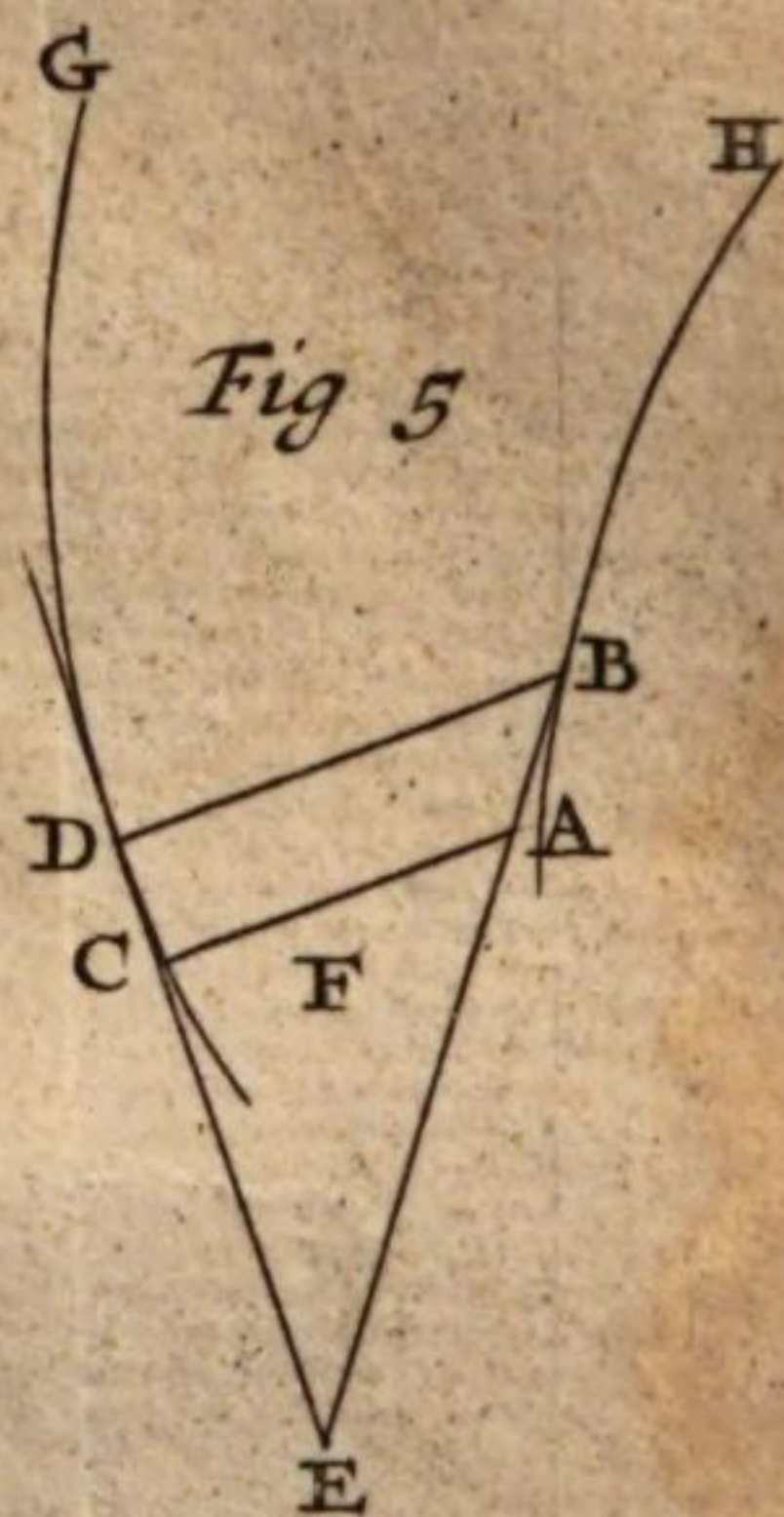
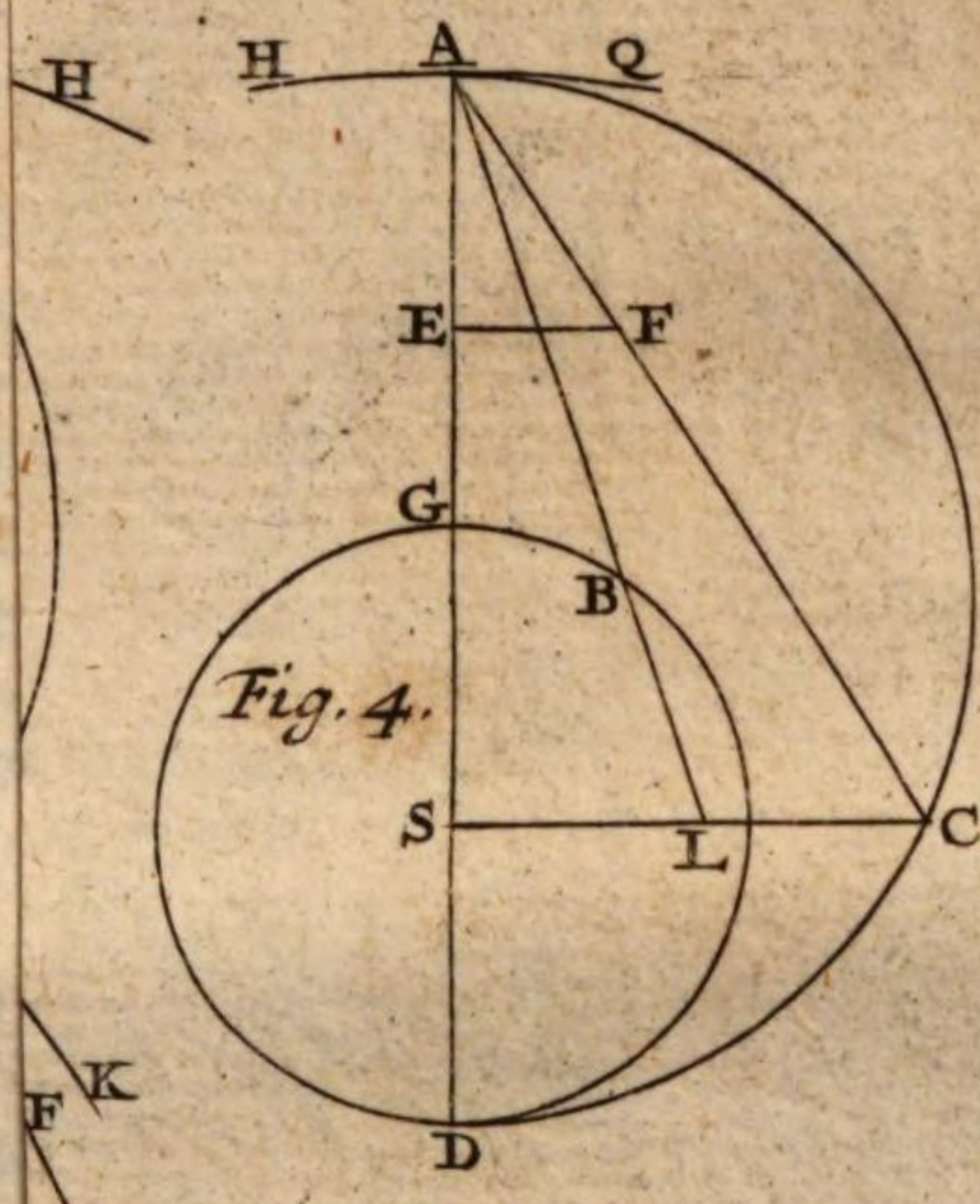
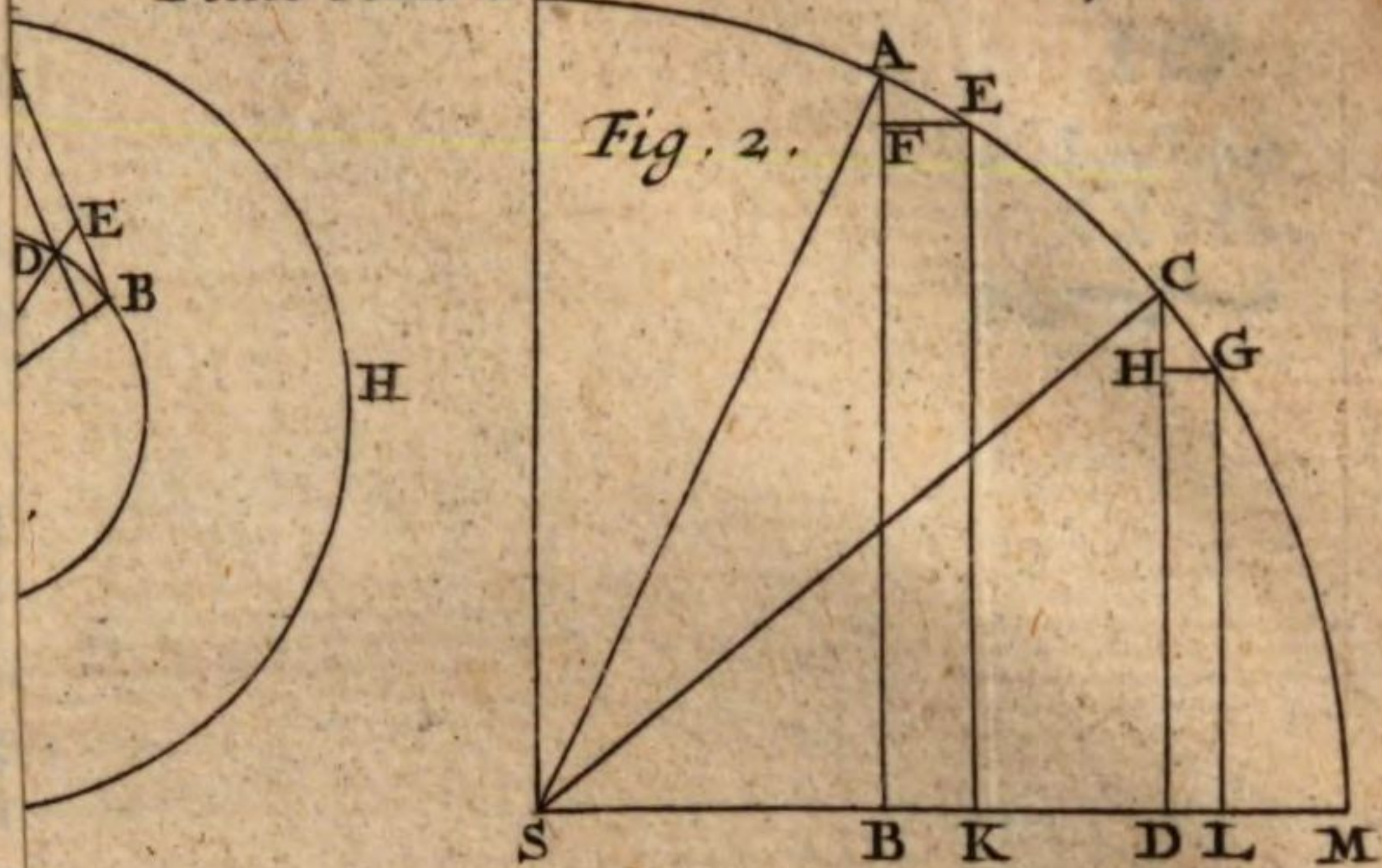
HAVING by the former Construction, or a rude Calculation, or even from an *Ephemeris*, found out the Day of the Station, find out by the most perfect *astronomical* Tables, for the Meridian of that Day, the Place of the Sun; as also the Planets *heliocentrick* and *geocentrick* Places, and the *Logarithms* of their Distances from the Sun; and to reduce their Motions to the same Plane, *curtate* the Di-

Lecture XXVII. stance of the Planet, and we have the Triangle STP , from the Principles of *Astronomy*, where S represents the Sun, T the Earth, and P the Planet. Draw TQ a Tangent to the Earth's Orbit, and PQ a Tangent to the Planet's Orbit, which meet in Q . Now, if the real Velocities of the Planet and Earth are as PQ and TQ , or as the Sines of the Angles PTQ and TPQ , it is plain that the Planet is then in the Situation required; that is, it will be there stationary.

* See the
Theor. Lect.
XXIII.

HAVING now the Distances ST , SP , we have the *Ratio* of their real Velocities, or of Tt and Pp . For the real mean Velocities of different Planets, that is, those Velocities with which at Distances equal to half the transverse Axes of the Orbits, they would describe Circles, are in a reciprocal subduplicate Proportion of the Axes. And * the mean Velocity of any Planet is to its Velocity in any other Point P or T , in a subduplicate Proportion of its Distance from the Sun, to its Distance from the other *Focus* of the Ellipse, which call respectively PF and TF : and putting R for half the transverse Axe of the superior Ellipse, and r for half the transverse Axe of the inferior, and then compounding the Ratio's, the Velocity of the inferior Planet will be to that of the superior, or Tt to Pp as $\sqrt{R \times SP \times TF}$ is to $\sqrt{r \times ST \times PF}$; and therefore we must have ready the Logarithm of this Ratio, reduced to the Plane of the Ecliptick.

FROM the same Distances we have likewise the Angles STQ and SPQ ; for the Radius is to the Sine of the Angle STQ , as $\sqrt{ST \times TF}$ is to half the conjugate Axis of the Orbit; and likewise the Radius is to the Sine of SPQ , as $\sqrt{SP \times PF}$ to half the conjugate Axis of the Planet's Orbit: or, which is more readily perform'd, say, as the Distance of the Planet, in its *Aphelion*, is to its Distance, in the *Perihelion*, so is the Tangent of half the Angle, by which it is distant from the *Perihelion*, to the Tangent of an Angle; which being subtracted





Subtracted from the foresaid half, leaves the Complement of the Angle SPQ to a Right, or its Excess above a Right, as it happens that this Angle is acute or obtuse. Reduce this Angle, if it is needful to the Plane of the Ecliptick; and these Things being done, subtract the Angle STQ from the Angle STP , and to the Angle SPQ add the Angle SPT , and we shall have the Angles QTP and QPT ; and, if the Sines of these Angles have the same Proportion that the real Velocities have in the Points T and P , the Estimation is right: But if not take the Difference of the Logarithms of each, or the Error of the first Position. And if the Ratio of the Velocities be less than the Ratio of the Sines, we must diminish the Angle TSP , by adding or subtracting a known mean Angle, such as will agree to one Day's Motion; and the contrary is to be done, if the Ratio of the Velocities be greater. And by a Calculation, just like the former, seek the Logarithms of the afore said *Ratio's*, for the Noon of the preceding or following Day, as the Case requires. Then compare the Differences of the foresaid Logarithms, or the Error of the first Position with the Error of the second; and the Sum of the Errors, if they be of several Kinds, or their Difference if they be of the same Sort, will be to 24 Hours, as either of the Errors to the Time between the Point of Station, and the Noon on which the assumed Error was found. This is plain to those who understand the Rule of False.

In this Manner the Stations of the Planets may be obtained within a few Minutes. But to take away the small Errors which may arise, by Reason the Logarithms do not uniformly increase as the Time, if any one pleases, he may renew the Calculation, for the Time just found out, and which is very near the Truth; and so bring out the true Time to a Minute: but there is no Need of this Correction, but in *Mercury* or *Mars*.

Lecture XXVII. FOR to make this plainer, we will add an Example of the Station of *Jupiter*, which lately happened on *November* the 9th 1717.

| November 9th at Noon. | | | | | Nov. 10 th at Noon. | | | | |
|-----------------------------------|----------|-----|----|----|--------------------------------|----------|-----|----|------------|
| | S. | gr. | ' | '' | | S. | gr. | ' | '' |
| The mean Anom. of ♃ | 9 | 10 | 00 | 00 | | 9 | 10 | 5 | 00 |
| Mean Motion of ☉ | 7 | 00 | 7 | 00 | | 7 | 1 | 6 | 8 |
| ♃ Helio. from the I
of ♄ | } | | | | 2 | 25 | 11 | 00 | 2 25 15 53 |
| ☉ Place from the I
of ♄ | } | | | | 6 | 28 | 53 | 17 | 6 29 54 00 |
| Log. Dist. of ♃ from
the Sun | } | | | | 5,720650 | 5,720680 | | | |
| Log. Dist. of ☉ from
the Sun | } | | | | 4,994267 | 4,994186 | | | |
| ♃ Geocentrick Place | 3 | 5 | 4 | 28 | | 3 | 5 | 4 | 27 |
| The Angle STP | 113 | 48 | 49 | | | 114 | 49 | 33 | |
| The Angle SPT | 9 | 53 | 28 | | | 9 | 48 | 34 | |
| The Angle STQ | 89 | 23 | 54 | | | 89 | 23 | 54 | |
| The Angle SPQ | 92 | 41 | 20 | | | 92 | 41 | 14 | |
| The Angle PTQ | 24 | 25 | 42 | | | 25 | 25 | 39 | |
| The Angle TPQ | 102 | 34 | 48 | | | 102 | 29 | 48 | |
| Log. of the Ratio of
Velocit. | } | | | | 0,368210 | 0,368321 | | | |
| Log. of the Ratio of
the Sines | } | | | | 0,372912 | 0,356757 | | | |
| <hr/> | | | | | <hr/> | | | | |
| The Error of the 1st Posit. | 0,004702 | | | | | 0,011564 | | | |
| The Error of the 2d Posit. | 0,011564 | | | | | | | | |

AND because one of these Errors does exceed the Truth, and the other is deficient from it, say, as 16266, the Sum of the Errors, is to 4702, so is 24 Hours to 6 Hours 56 Minutes. Hence we conclude the Time of the Station of *Jupiter* to have been *November* the 9th, six Hours and 56 Minutes after Noon.

LECTURE



LECTURE XXVIII.

*Of the Division of TIME, and its
Parts.*

THE Parts of *Time* are known to all Men; being Days, Hours, Weeks, Months, and Years. A natural Day is determined by the apparent Motion of the Sun from East to West, and is that Space of *Time* that flows while the Sun goes from any Meridian, or horary Circle, till it arrives to the same again. It is called natural, to distinguish it from that Signification of the Word Day, which is opposed to Night, and which are called the artificial Day.

*A natural
Day.*

ALL Nations do not begin their Day alike. The *Babylonians* counted the Beginning of their Day from the Sun-rising. The *Jews* formerly, and the *Athenians*, from Sun-setting; which the *Italians*, *Austrians*, and *Bohemians*, do at this Time; so that when the Sun comes to the Western Horizon, they count the twenty-fourth Hour; and the Hour after the Sun is set, they call the first Hour.

*The different
Beginnings
of the Day.*

THEY who begin their Day at Sun-rising, have this Advantage, that their Hours tell them how much Time is already gone since Sun-rising; and they who reckon their Hours from Sun-setting, have this Use of it, that they know how long it is to Sun-setting, that they may proportion their Journies and Labours for that Time. But both of them have this Incon-

Lecture XXVIII. convenience, that they cannot immediately tell by their Hours the Times of Mid-day or Mid-night, but they must compute by the Length of the Day-time, or the Season of the Year; for in different Seasons, the Time of Mid-day is reckoned by different Hours. The *Egyptians* antiently began their Day at Mid-night, from whom *Hipparchus*, that antient and famous *Astronomer*, brought that Way of reckoning into *Astronomy*. And *Copernicus*, and some other *Astronomers*, have followed him therein. But the much greater Part of the *Astronomers* have thought it better to begin their Day from Noon. Yet the Method of Beginning from Mid-night is received in *Britain*, *France*, *Spain*, and most of the Nations in *Europe*.

THERE are two Sorts of Hours, equal and unequal. An equal Hour is the twenty-fourth Part of the natural Day. Besides the Division of Hours received by the Vulgar into half Hours, Quarters, and half Quarters, we now generally follow the *Astronomical* Division, and reckon every Hour 60 Minutes, in every Minute 60 Seconds, and in every Second 60 Thirds, &c.

AN unequal Hour is the twelfth Part of the artificial Day, or the twelfth Part of the Night; and it is called the *temporary Hour*, because at different Seasons of the Year, it is of a different Length. For a diurnal Hour in the Summer is longer than one in the Winter; a Night Hour is shorter. But in the equinoctial Day, the Hours in the Day and Night are equal to each other; and therefore the equal Hours are called *Equinoctial*. The *Jews* and *Romans* formerly used these Hours, and the *Turks* reckon by them at this Day, and their Noon always falls upon the sixth Hour of the Day. These Hours are also called *planetary Hours*, because in every Hour they supposed one of the seven Planets to preside over the World, and they took it by Turns; so that the first Hour after Sun-rising fell on *Sunday* to the *Sun*, the next to *Venus*, the third to *Mercury*; and the rest in order to the *Moon*, *Saturn*, *Jupiter*, and *Mars*. By this Means, on the first Hour of the next Day the *Moon* presided, and on that Account

Account gave the Name to that Day ; and the Lecture Days of the Week by this Method, have had their XXVIII. Names from the Planet that governed the first  Hour, 'till the End of the Week.

A Week is a System of seven Days, in which *A Week.* each Day is distinguished by a different Name. The Christian Church called the first Day of the Week the *Lord's Day*, the Vulgar term it *Sunday*, and none but the *Phanaticks* of our Time ever called it *Sabbath-day*. The rest of the Days of the Week were called *Feriæ*, *Munday* the second *Feria*, *Tuesday* the third *Feria*, &c. and *Saturday* they also called the *Sabbath-day*. But the common People use the same Names that were given by the *Romans*; each Day being denominated from a Planet.

A Month is properly that Space of Time the *A Month.* Moon takes to perform its Course in the *Zodiack*; which, in the Space of a Year, it runs over twelve Times. There is another Month nearly equal to it, which is measured by the Motion of the Sun, and is that Space of Time, in which the Sun moves through one Sign, or twelfth Part of the *Ecliptick*: These Months are properly *Astronomical*. A Civil Month is different from them, and consists of a certain Number of Days, fewer or more according to the Laws and Ordinances of the Kingdom or Republick, in which they are observed. The *Egyptians* made each Month to consist of 30 Days, and the Year consisting of 5 Days more than 12 Months, they added them to the End of the Year, and called them *Epogamenæ*.

THE Year is either *Astronomical* or Civil; *The Civil* both Kinds of the *Astronomical* Years, viz. the *Year of two* *Tropical* and *Periodical*, we have already defined *Sorts.* in our XXII Lecture. The Civil Year is the same with the Political Year, established by the Laws of a Country, and is of two Kinds, Lunar or Solar, according as it is designed to be regulated by the Motions of the Moon or Sun. There are two Sorts of Lunar Years, the one moveable,

Lecture moveable, the other fixed: The moveable Year XXVIII. consists of twelve synodick Months, or of twelve Lunations which are completed in 354 Days, and after that Time the Year begins again. This Year is less than the Solar Year, which brings back all the Seasons by eleven Days. And therefore, the Beginnings of such Years move through all the Seasons, and that in the Space of 32 Years: This Form of a Year is observed by the *Turks* and *Mahometans*.

The move-
able Lunar
Year.

The fixed
Lunar Year.

SINCE twelve Lunations is less than a Solar Year by eleven Days, three Lunar Years are less than three Solar Years by 33 Days; and therefore, to keep the Months in the same Seasons and Times of the Solar Year, to the third Year there is a whole Month added, and it consists of 13 Months: And this is done as often as is needful, to keeping the Beginning of the Year always in the same Season. And the Month added, is called an *Embolimæan* or Intercalary Month. In 19 Years there are seven such Months, and this Kind of Lunar Year is called Fixed, and was observed by the *Greeks*, whom the *Romans* followed in this Matter 'till the Times of *Julius Cæsar*.

The Solar
Year.

THE Solar Year, which is made conformable to the Motion of the Sun, is likewise of two Kinds, moveable and immoveable. The moveable is called the *Egyptian* Year, because observed in that Country: And it consists of 365 Days, and is less than the tropical Year, in which the Sun runs his Course in the Ecliptick, by almost six Hours. By the neglecting of these six Hours, it happens, that four such Years are less than four tropical solar Years by a whole Day. And therefore, in four Times 365 Years, that is, in 1460 Years, the Beginning of the Years moves through all the Seasons of the Year.

SINCE therefore an *Egyptian Year* is less than a true Solar Year, by almost six Hours; that all the Years may go on according to the Sun's Motion, a Regard must be had to these six Hours. But it is requisite also, that the Political Year have

have always the same Beginning, and that it commence with the Day; for it would be inconvenient to have the Year begin sometimes at one Hour of the Day, sometimes at another; which would necessarily fall out, if we added to every Year six Hours. Now, these Hours, amounting in three Years to eighteen Hours, if they be added to the six Hours of the fourth Year, will make a whole Day: Therefore, this Day being added to the fourth Year, will reduce it again to be even with the Motion of the Sun. *Julius Cæsar* perceiving this, ordered that every fourth Year should have an Intercalary Day, which therefore consists of 366 Days; and the Day added is put in the Month of *February*. And because in the common Year the 24th of *February*, in the *Roman* Way of Reckoning, was the sixth of the *Kalends* of *March*, or the sixth Day before the *Kalends* of *March*, *Cæsar* ordered that for that Year, there should be two Sixths, or that the Sixth of the *Kalends* of *March* should be twice reckoned; upon which Account the Year was called *Bissextile*, which we name the Leap-Year. This Form of a Year was instituted by *Julius Cæsar*, who was then High-Priest among the *Romans*, and was called the *Julian* Year; whose Nature is, that every fourth Year consists of 366 Days, and the other three only of 365.

BUT it must be acknowledged, that the Time appointed by *Julius Cæsar* for the solar Year is too much; for the Sun finishes his Course in the *Ecliptick* in 365 Days, 5 Hours, and 49 Minutes, and therefore he begins again his Round, eleven Minutes before the Civil Year is ended. So that if the Sun in any Year has entered the Equinox upon the 20th of *March* at Noon-day, after 4 Years he will arrive at the Equinox 44 Minutes before Noon, and the fourth Year after that, he will be there 1 Hour 28 Min. before Noon; and so every Year 11 Minutes sooner than by this Reckoning; so that in 131 Years he will anticipate or enter the Equinox a whole Day before the 20th of *March*:

Lecture
XXVIII.



March: And therefore the celestial Equinox will not always fall upon the same Day of the Month, but by Degrees it will move towards the Beginning of the Year: And this so sensibly, in Compass of Time, that it cannot be doubted.

HENCE in the Time of the Council of *Nice*, (about which Time, the Terms were settled for observing *Easter*) the vernal Equinox fell upon the twenty-first of *March*: But the Equinox continually falling backwards in the Year, in the Year of *Christ* 1582, when the *Kalendar* was corrected, it was found, that the Sun entered the equinoctial Circle on the 11th of *March*, and was departed ten whole Days from its former Place in the Year: And therefore, when *Gregory* the XIIIth of that Name, Bishop of *Rome*, designed to place the Equinocties in their former Situation, in respect of the Year; he took those ten Days out of the *Kalendar* that Year, and ordered, that the Eleventh of *March* should be reckoned as the twenty-first: And to prevent the Seasons of the Year from going backwards as they did before; he ordained, that every hundreth Year, which in the *Julian* Form was to be a *Bissextile*, should be a common Year, and consist only of 365 Days; but because that was too much, every four hundredth was to remain *Bissextile*. This new Form of the Year being established by the Authority of the Bishop of *Rome*, *Gregory* XIII. is called by his Name the *Gregorian* Year, and is received in *France*, *Spain*, *Italy*, *Germany*, and in all the Countries where the *Pope's* Authority is acknowledged; as likewise, lately in several where the reformed Religion is observed. Yet in *Britain*, and other Northern Countries, the *Julian* Form of the Year is still retained.

The Grego-
rian Year.

THE *Persians* observe the *Egyptian* Form of the Years to this Day, whence it is that Equinocties remain not in the same Month, but move thro' them all; and after a Period of about 1460 Years, the Beginning of their Year falls in with the same Time of the true Solar Year. This Time or Period

riod is called the *Great Canicular Year*, or the *Sothiacal* Period, because it takes its Beginning on the first Day of the Month *Thoth*, or the first Day of that Year, when the Dog-Star rises heliacally, for the Word *Sothis*, in the *Egyptian* Language, signifies the Dog, which in *Greek* is called *ἀσπερδων*, that is, the Dog-Star, which the *Astronomers* name *Sirius*. 

THE Antients not only distinguished the Times by Years, but by several Revolutions or Collections of Years; such was the *Jubilee* of 49 or 50 Years; an Age consisted of an hundred Years. But among the *Greeks*, the *Olympiads* were esteemed the most Famous, each of them containing the Space of four Years.

As in the Heavens there are certain Points, from which the *Astronomers* begin their Computations of the Planets Motions; so also there must be certain Points, or Instants of Time, from which as from Roots, all Calculations must begin: And all memorable Actions are disposed and recorded, according to the Series of Years which follow from that Root. These Roots are called *Epoch's* or *ÆRA's*, from which we generally count our Years and Times. The most famous, best known, and most used by us, is that which is reckoned from the Nativity of our Lord *Jesus*, which begins at the *Kalends* of *January*, that immediately followed his Birth.

Now, although this *Epoch* is generally received by Christians, yet the *English* and *Irish* have an *Epoch* a whole Year posterior to it, which they commonly use in all Publick and Ecclesiastical Affairs: For they do not begin their Year with the first of *January* that follows the Nativity, but with the Feast of the Conception or Incarnation, which is observed on the 25th of *March*; and therefore, it is, that the *English* reckon from the Feast of *Lady-Day* 1718, that there are compleated 1717 Years; but from the Birth of our Lord, to the Feast of the Nativity of the Year 1717, they number

Lecture number only 1716 Years elapsed; whereas all the XXVIII. rest of the Christian World count 1717 Years.

~ IN this Affair, they exactly agree with *Dionysius*, surnamed *the Less*, according to whom, *Christ* is supposed to have been conceived the 8th of the Kalends of *April*, in the first Year of this *Æ R A*; and was born the Winter following, at the End of the 46th Year, from the Reformation of the Kalendar by *Julius Cæsar*. This Way of computing was at first universally received; but afterwards, by Degrees and tacitely, all Nations receded from it; so that it does only now take Place in *England*, and the Dominions thereof; and the common Opinion is, that *Christ* was born the Winter preceding the Time that *Dionysius* reckoned the Conception to have been; and by this Means, they make *Christ* to have been a Year before *Dionysius*, the Author of the *Æra*, supposed he was born.

BUT yet for all this, the *English*, for the greatest Part of the Year, design it by the same Number that the rest of the Christian World does: But for three Months, *viz.* from the Kalends of *January* to the 8th of the Kalends of *April*, they write one less.

THERE is likewise the *Epocha* of the *Creation*, which is much noted; yet about it there are great Controversies among the *Chronologists*; some affirming, that the World was created 3950 Years before the Birth of *Christ*; others again say, that at the Birth of *Christ*, the Age of the World was 3983 Years. The *Greek Church*, and the Emperors of the East, used an *Epocha* of the *Creation*, which was much more antient, and makes the World to have been created 5509 Years before the Coming of *Christ*.

AMONG the prophane Authors, the ancientest *Epocha* is that of the *Olympiads*, which begun at the Summer of the Year 777, preceding the Birth of *Christ*, and on the Kalends of *July*.

THE *Epoch* of *Rome*, or of the Building of the City, is not long after the *Olympiads*, and there
are

are two of them, the *Varronian* and *Capitolian*; Lecture according to the first, the City was built the Year XXVIII. before *Christ* 753; according to the other, it was  in the Year 752.

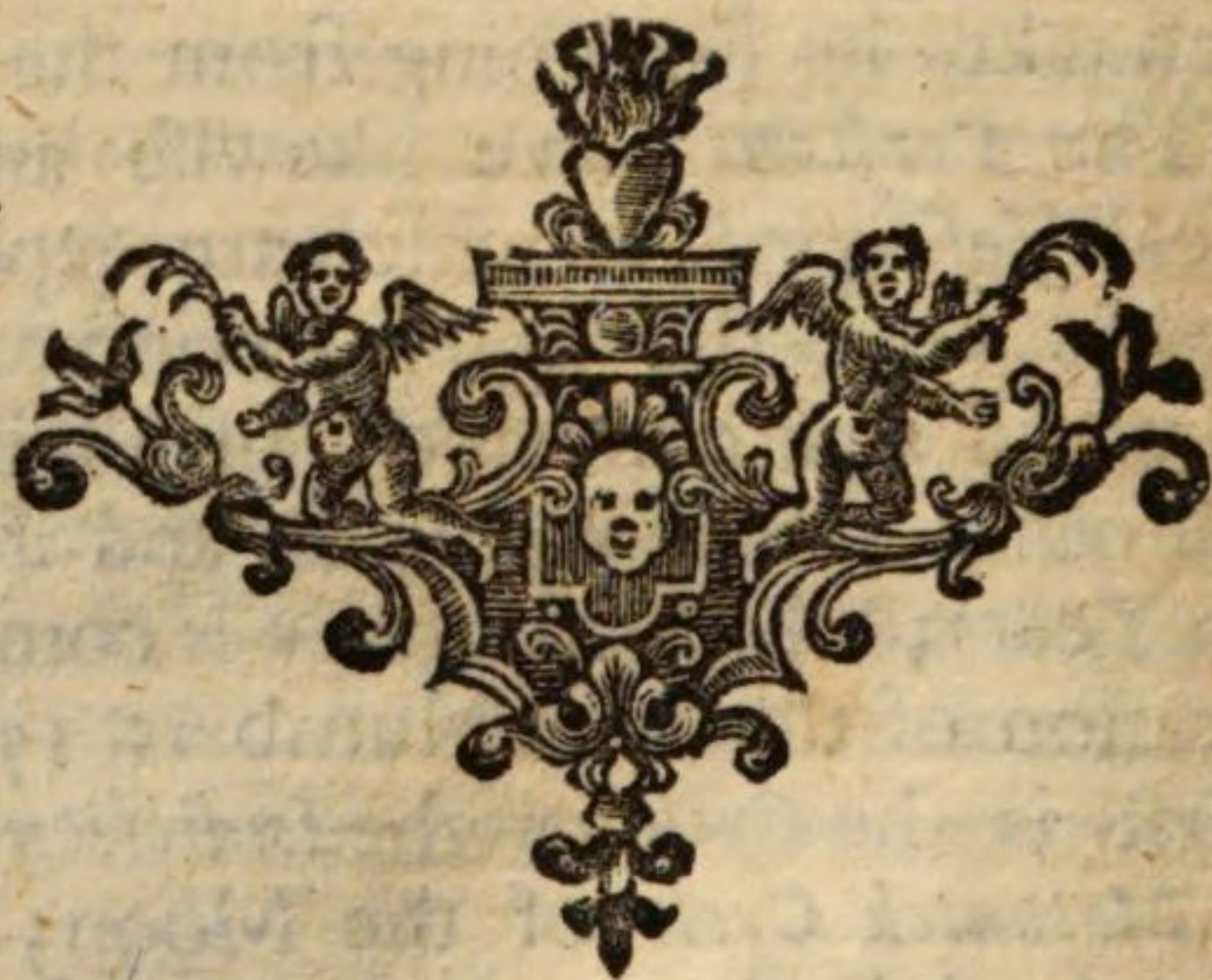
THE *Æra* of *Nabonasser* has always been famous among the *Astronomers*, and began on the 6th of *February* of the *Julian* Year carried backward, and before *Christ* 747. And because that Day was then the first of the *Egyptian* Year, *Ptolemy*, and after him *Copernicus*, computed the Motion of the Stars, according to that *Æra*, by *Egyptian* Years; for the *Egyptian* Year is very convenient for *Astronomical* Calculations, it being interrupted by no intercalary Days.

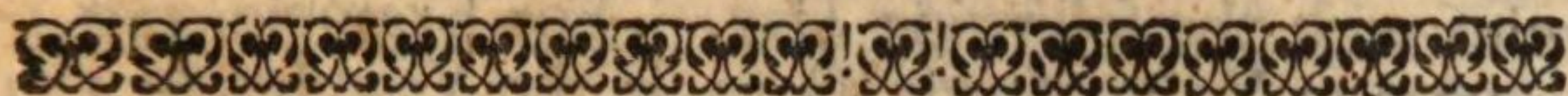
AFTER this, we have another *Epocha* of the Death of *Alexander* the Great, the three Hundred and twenty fourth Year before *Christ*, on the 12th of *November*; which was then the first Day of the *Egyptian* Year. *Theon*, *Albategnius*, and some others, have computed from thence according to the *Egyptian* Year. Between the two *Æra*'s of *Nabonasser*, and of the Death of *Alexander*, there are precisely 424 *Egyptian* Years. The *Abissines* reckon by another *Æra*, which is called the *Æra of the Martyrs* or of *Dioclesian*. The *Turks* and *Arabians* reckon by an *Æra*, which they call the *Hegira*, which takes its Beginning from the Flight of *Mahomet*. The *Persians* have likewise an *Epoch*, which they call *Jesdegird*; all which are explained by the *Chronologists*. But the *Julian* Period, seems to be the most useful and convenient of all, it including almost all other *Æra*'s within it, and it is a Period of 7980 Years; which Number is composed by the Multiplication of the three Numbers, 15, 19, and 28. The first is the *Cycle* of the *Indiction*; the second is the *Metonick Cycle* of the Moon; and the third is the *Cycle* of the Sun. And the first Year of this Period was that wherein all these three *Cycles* began together. I will here add a Table; which gives the first Year of the several *Æras*, and reduces

Lecture XXVIII. duces them to the Years of the *Julian* Period, and to the Years before or after the Birth of *Christ*.



| | Years
before
Christ. | Years of
the Julian
Period. |
|---|----------------------------|-----------------------------------|
| The Creation of the World accord-
ding to the <i>Greek</i> Emperors, | 5508 | |
| The Common <i>Æra</i> of the Creation, | 3950 | 765 |
| The Beginning of the <i>Olympiads</i> , | 776 | 3938 |
| The Building of <i>Rome</i> , according to
<i>Varro</i> , | 753 | 3961 |
| The Building of <i>Rome</i> , according to
the Registers of the Capitol, | 752 | 3962 |
| The <i>ÆRA</i> of <i>Nabonassar</i> , | 747 | 3967 |
| The Death of <i>Alexander</i> the Great, | 324 | 4390 |
| | Years
after
Christ. | |
| The common Christian Epoch, | I | 4714 |
| The <i>Dioclesian</i> <i>Æra</i> , | 284 | 4997 |
| The <i>Hegira</i> of the <i>Turks</i> , | 622 | 5335 |
| The <i>Jesdegird</i> of the <i>Persians</i> , | 632 | 5345 |





LECTURE XXIX.

Of the Kalendars. Of Cycles and
Periods.

THE *Kalendar* is a Table, in which are ^{The Kalendar.} set down all the Days of the Year, in a regular Disposition, according to their Months, with a Distribution of them into Weeks. The Vigils, Holy-days, and Law-days, together with the *University* Terms, are likewise annexed. The Distribution of Days into Weeks is made by the seven first Letters of the Alphabet, A B C D E F G. Beginning at the first of *January*, to it place the Letter A; to the second of *January* B is joined; to the third C; and so on to the seventh, where G is figured: And then again beginning with A, which is placed at the eighth Day, B will be at the Ninth, C at the Tenth; and so continually repeating the Series of these seven Letters, each Day of the Year has one of those Letters in the *Kalendar*. By this Means the last of *December* has the Letter A joined to it. For if the 365 Days which are in a Year, be divided by seven, we shall have 52 Weeks, and one Day over. If there had been no Day over, all the Years would constantly begin on the same Day of the Week; and each Day of a Month would constantly have fallen upon the same Day of the Week. But now, because, besides the 52 Weeks in the Year, there is one Day more, from thence it happens, that

B b

on

Lecture on whatever Day of the Week the Year begins, it
 XXIX. ends upon the same Day; and the next Year begins with the following Day. For Example, in a common Year of 365 Days, if the Year begin on a *Sunday*, it will end on a *Sunday*; and the first Day of the next Year will be *Monday*.

THE Letters being ranked in this Order; that Letter which answers to the first *Sunday* of *January*, in a common Year, will shew all the *Sundays* throughout the Year; and to whatever Days in the rest of the Months that Letter is put, these Days are all *Sundays*; and therefore that Letter is called the *Dominical* or *Sunday* Letter of that Year. So also whatever Letter is joined to the first *Monday* in *January*, the same, as often as it is repeated in the *Kalendar*, shews the *Mondays* throughout the Year.

IF the first Day of *January* be a *Sunday*, the last Day of the Year, as I have said, will likewise be a *Sunday*; and therefore, the next Year will begin on *Monday*, and the *Sunday* will fall on the seventh Day, to which is annexed the Letter G; which therefore will be the *Sunday* Letter for all that Year: And since the Year began on *Monday*, it will also end on that Day; and the following Year will begin on a *Tuesday*, and the first *Sunday* will fall upon the sixth of *January*, to which Day is adjoined the Letter F, which is the *Sunday* Letter for that Year. And in the same Manner for the Year next following, the *Dominical* Letter will be E: By this Means the *Sunday* Letters will go in a retrograde Order by G F E D C B A. In the yearly *Kalendars*, which we call *Almanacks*, which is an *Arabick* Word, the *Dominical* Letter, to distinguish it the better, is made a Capital, and all the rest are of a smaller Form. By this Means, at one View, we shall see all the *Sundays* in the Year.

IF all the Years were *Egyptian* Years of 365 Days, after a Period of seven Years, the same Days of the Month would return to fall on the same Days of the Week. But we observing the *Julian* Year, where every fourth is *Bissextile*, or consists of 366 Days, in which, besides the 52 Weeks, there are two Days over.

over. If that Year should begin with a *Sunday*, it will end on a *Monday*; and the next Year will begin on *Tuesday*; and the first *Sunday* of that Year will be on the sixth of *January*, to which is annexed the Letter F, which will be the *Dominical* Letter for the Year following that Leap-year, whose *Dominical* Letter was A.

By this Means, the *Bissextile* Year returning every fourth Year, the Series of the *Dominical* Letters, succeeding each other, is interrupted, and does not return in Order till after four times seven, or twenty-eight Years. Hence ariseth the *Cycle* of 28 Years, which is called the *Cycle* of the Sun; which being completed, the Days of the Months return in the same Order to the same Days of the Week. In this *Cycle* all the *Bissextile* Years have two *Dominical* Letters, the first of which takes Place till the 24th or 25th of *February*, and the other serves for all the rest of the Year: For in the *Bissextile* Year the 24th and 25th of *February* are esteemed as one and the same Day, and both of them have the same Letter F annexed to them; and by this the Order of the *Sunday* Letter is interrupted. For Example, If in the Beginning of the Year the *Sunday* Letter is E, the 24th of *February* will fall upon a *Monday*, and the 25th on a *Tuesday*; both which Days are marked with the Letter F; and therefore the following Letter G, which shewed the *Tuesdays* before, will now point out the *Wednesdays*; and the next *Sunday* will fall upon the sixth of *March*, to which, in the *Kalendar*, is annexed the Letter D; which will point out the *Sundays* for all the rest of the Year, and then becomes the *Dominical* Letter.

THE first Year of the *Cycle* of the Sun is a *Bissextile*; and the *Dominical* Letters, answering to it, are G and F. For the second Year the *Sunday* Letter is E, for the third D, the fourth C; and again, the fifth Year of the *Cycle* being a *Bissextile*, has two *Dominical* Letters B and A; and so in the rest. The following small Table shews what *Dominical* Letter belongs to each Year of the *Cycle*.

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XXIX.

| | | | | | | | | | | | | | |
|---|----|---|----|----|----|----|----|----|----|----|----|----|----|
| 1 | GF | 5 | BA | 9 | DC | 13 | FE | 17 | AG | 21 | CB | 25 | ED |
| 2 | E | 6 | G | 10 | B | 14 | D | 18 | F | 22 | A | 2 | C |
| 3 | D | 7 | F | 11 | A | 15 | C | 19 | E | 23 | G | 27 | B |
| 4 | C | 8 | E | 12 | G | 16 | B | 20 | D | 24 | F | 28 | A |

To find the Year of the Cycle of the Sun, for any Year of the Christian Æra; To the current Year of Christ add 9, because from the beginning of the Cycle, till the first Year of Christ, there were 9 Years past: Divide the Sum by 28, the Quotient shews the Number of Cycles, that have revolved since the first Year before Christ, till the current Year; and the Remainder, if there be any, is the current Year of the Cycle; but if there be no Remainder, then 28 is the current Year of the solar Cycle.

The move-
able Feasts.

The Feast of
Easter.

BESIDES the fixed and settled Feasts, which are always on certain and determined Days of the Year, there are other Feasts and Holydays, which are moveable, and in different Years fall upon different Days of the Month; and sometimes in different Months: These Holydays are not regulated by the Motion of the Sun, but by that of the Moon: Such was the Feast of the *Passover*, instituted by God himself, for the *Jews* to observe; and is succeeded by the Christian *Easter*, in Memory of our *Saviour's* Resurrection. God ordained that the *Passover* should be celebrated in the first Month, the 14th Day of the Month at Even. See *Leviticus Chap. XIII.* Now the *Jewish* Year was a lunar Year, and so ordered by intercalary Months, that the Month, whose fourteenth Day, or whose full Moon, fell either on the Vernal Equinox, or next after it, was reckoned the first Month of the Year. The Christian Church was willing to observe the same Method in celebrating of *Easter*. But yet, to distinguish it from the *Jewish* *Passover*, would not keep the Feast

Feast on the 14th Day, but on the *Sunday* after, Lecture
because our Lord rose upon the *Sunday* after the XXIX.
Jewish Passover. 

THEREFORE for determining the Time for the Celebration of *Easter*, we must define the Time of the Equinox, which was believed to be fixed to the twenty-first of *March*, and the Fathers thought it could never happen on any other Day; and therefore they made their *Kalendar* upon that Supposition. Then they called that the *Paschal* or first Month, whose 14th Day, or Full Moon, fell on the equinoctial Day, that is, on the 21st of *March*, or next followed the 21st of *March*. But because the *Jewish* Months were lunar Months, the 14th Day immediately preceded the Full Moon; therefore, for the Time of the Observation of *Easter*, we must have a Regard to the Motion of the Moon, and the Times of New-Moons and Full-Moons must be found. The *Jews* had no other Way of finding the New-Moon, but by observing it; and when the Moon first appeared to emerge out of the Sun's Rays, or to rise in the Evening heliacally, that Day they called the first Day of the Moon or Month. The Christian Church computed their Lunations by the *Metonick Cycle* of 19 Years; and therefore, they inserted this *Cycle* in their *Kalendars*, and called its Numbers the *Primes* or *Gold-numbers*, by which they determined the Times of the Lunations.

THE *Metonick Cycle*, called so from its In-
ventor *Meton*, is also termed the *Cycle* of the
Moon, and is a Period of 19 Years; which when
they are compleated, the New-Moons and Full-
Moons return on the same Days of the Month;
so that on whatever Days the New and Full-
Moons fall this Year, 19 Years hence they will
happen on the very same Days of the Months,
as *Meton*, and the Fathers of the Primitive Church
thought. And therefore, at the Time of the
Council of *Nice*, when the Way of settling the
Time for observing the Feast of *Easter* was
established, the Numbers of the lunar *Cycle* were

The Cycle
of the Moon,
or the Me-
tonick
Cycle.

Lecture XXIX. inserted in the *Kalendar*, which upon the Account of their excellent Use, were set in golden Letters, and the Year of the *Cycle* for any Year, was called the Golden Number of that Year.

THE Golden Numbers were placed in the *Kalendar*, according to the following Method; taking any Year for the Beginning of the *Cycle*, which they reckoned by the Number 1, and observing, every Month, the Days on which the New-Moons happened that Year, just by those Days they joined the Number 1. And because, in that Year, the New-Moons happened on the twenty-third of *January*, the twenty-first of *February*, the twenty-third of *March*, the twenty-first of *April*, the twenty-first of *May*, the nineteenth of *June*, and so in the rest; just by those Days in the Column of the Golden Number they put the Number 1. The second Year observing the New Moons, to the Days on which they happened they inscribed the Number 2, viz. to the twelfth of *January*, the tenth of *February*, the twelfth of *March*, and tenth of *April*, and so on in the rest of the Months. The same Thing was done the third Year, annexing the Number 3 to all the Days the Moon changed in that Year; and so on, in the following Years, till the whole Period of 19 Years was compleated. But the most accurate Disposition of the golden Numbers is by the mean Lunations, as they are set down in the *Astronomical* Tables, for every Month and each Year of the lunar *Cycle*; and fixing, according to that Computation, the Character of the Year to each Day on which the Lunation happens.

BECAUSE a lunar *Astronomical* Month consists of 29 Days, 12 Hours, 44 Minutes and 3 Seconds; the common People, who cannot distinguish the small Particles of Time, make the lunar Months to consist of entire Days without Fractions, and on that Account they alternately put one Month of 30 Days, and the next of 29 Days. These are called Hollow or Cave, that

that is, deficient Months, the others Full; the 12 Hours over the 29 Days, requiring this Alternation: But because there are 44 Minutes besides, which is almost three Quarters of an Hour, in every Lunation; in 32 Lunations these Minutes will make up a whole Day, which is to be added to a hollow Month; and by this Means the Lunations of the *Kalendar* will nearly agree with those of the Heavens.

IF we know the Year of the lunar Cycle, which in our *Liturgy* is called the *Prime*, we have the Days of the Moon's Change throughout the Year; for in each Month, the Golden Number or *Prime* is set to the Day the Change happens on; and adding to that 14 Days, we shall have the Day of Full-Moon.

THE Antients imagined, that the Cycle of 19 Years did exactly compleat 235 Lunations; and therefore, after the Revolution of that Time, that the New-Moons not only fell on the same Days of the Month, but likewise on the same Hours of the Day, which is not true: For in 19 *Julian* Years, there are 6939 Days and 18 Hours. But if to every Lunation we allow 29 Days, 12 Hours, 44 Minutes, 3 Seconds, which the Motion of the Moon requires; 235 Lunations will make 6939 Days, 16 Hours, 31 Minutes, and 45 Seconds. Therefore 235 Lunations are not equal to 19 *Julian* Years, but are less by one Hour and an half. And consequently, the New-Moons, after 19 Years, will not return to the same Hour, but will be an Hour and a half sooner; and in 304 Years they will anticipate a whole Day. And therefore the Golden Number will, precisely enough for common Use, shew the Lunations in the Space of three Centuries, without the Error of one Day. In the Council of *Nice*, when the Cycle of the Moon was fitted to the *Kalendar*, and some Centuries afterwards, it did nearly enough give the Time of the New Moons. But the Lunations in every 304 Years anticipating a whole Day, they now happen almost five Days

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sooner than they should do, according to the Rule of the Golden Number: Notwithstanding of this, the Church of *England* retains the Way of computing the Lunations by the Golden Number, as it was disposed in the Kalendar at the Time of the *Nicene* Council: And the New Moons, computed in that Manner, are called Ecclesiastical New-Moons, to distinguish them from the true ones, in the Heavens: And the general Table or Rule for finding *Easter* for ever, which is in our Liturgy, by the Golden Number and Dominical Letter, is made according to that Disposition of the Golden Number.

IN the first Year of the Christian *Æra*, 2 was the Golden Number; and therefore, if to the current Year of *Christ* we add 1, and divide the Sum by 19, the Remainder, after the Quotient, will give the Golden Number.

FROM the Cycles of the Sun and Moon multiplied into one another, arises a third Period of 532 Years, which is call'd the *Victorian* or *Dionysian* Period: And after the Completion of this Period, not only the New and Full-Moons return to the same Days of the Month; but also the Days of the Months return to the same Days of the Week; and therefore the *Dominical* Letters, and the moveable Feasts, return again in the same Order. Hence this Cycle is called the great *Paschal* Cycle.

TO find the Year of the *Dionysian* Period for any Year of *Christ*, to the current Year add the Number 457, and divide the Sum by 532, the Remainder, after the Quotient, is the Year of the Period.

IT is a Problem of another Kind: *Having the Cycles of the Sun and Moon, to find the Year of the Dionysian Period.* For Example, suppose the Year of the Cycle of the Moon be to 17, and of the Sun 21: To solve this Problem, it is required to find a Number, which, when it is divided by 19, leaves 17, and when it is divided by 28, leaves 21. To find this, let it be requir'd
to

to find two Numbers, one of which will divide exactly by 28, without a Remainder, but when it is divided by 19, leaves 17; and another Number, which will divide exactly, without a Remainder by 19, but when it is divided by 28, leaves 21: It is plain, that the Sum of these two Numbers will answer the Question. Lecture XXIX.

WE will here shew the analytical Investigation of these two Numbers. We will suppose the first Number to be $28x$, for it is a Multiple of 28; and because this Number, divided by 19, leaves 17; if we take 17 from it, the Remainder, divided by 19, will be a Number; since then 19 divides $28x - 17$, and it also divides $19x$, therefore it will divide their Difference, which is $9x - 17$; consequently $\frac{9x - 17}{19}$ is a Number.

Call that Number n , consequently $9x - 17 = 19n$, and $9x = 19n + 17$, and $x = \frac{19n + 17}{9}$

and because x is an intire Number, 9 must divide $19n + 17$, but 9 divides $18n + 9$; therefore it will divide the Remainder $n + 8$, and therefore $\frac{n + 8}{9}$ is a Number. Let that Number be 1, and

n will be $= 1$, and $x = 4$; consequently, $28x = 112 =$ to the first Number to be found. Suppose, the second Number to be $19y$; for it must be a Multiple of 19; therefore $\frac{19y - 21}{28}$

is an integer Number; suppose it to be n ; then $19y - 21 = 28n$, and $y = \frac{28n + 21}{19}$, which,

must likewise be an intire Number; and therefore $28n + 21$, will be divided by 19: But 19 divides $19n + 19$; wherefore it will divide the Remainder $9n + 2$, and $\frac{9n + 2}{19}$ is an intire Number; suppose

it $= p$; then is $9n + 2 = 19p$, and $n = \frac{19p - 2}{9}$ therefore

Lecture therefore 9 must divide $19p - 2$; but it divides
 XXIX. $18p$, therefore it must also divide $p - 2$, and
 ~~~~~  $\frac{p-2}{9}$  is an Integer or 0: Let it be equal to 0, then

is  $p = 2$ , and  $\frac{19p-2}{9} = n = 4$ , and  $19y = 28n$

$+ 21 = 133$ ; therefore one of the Numbers is 112, and the other is 133, whose Sum is 245, the Number requir'd: And whenever the Cycle of the Sun is 21, and that of the Moon 17, the Year of the *Dionysian* Period is 245.

THE same Problem may be otherwise solved, by stated and constant Multipliers, which are such, that one of them can be divided by 28, without any Remainder; but if it be divided by 19, there remains 1: The other will divide by 19 without a Remainder; but when it is divided by 28, there is a Remainder of 1: Such Numbers are found in the same Way, as the preceding Numbers were; viz. I suppose the first to be  $28x$ , and the other  $19y$ ; wherefore 19 will divide the Number  $28x - 1$ , without any Remainder; and therefore it will divide  $9x - 1$  without a Remainder, and  $\frac{9x-1}{19}$  will be a whole Number: Suppose it

equal to  $n$ ; then  $x = \frac{19n+1}{9}$ ; therefore  $\frac{n+1}{9}$  is an intire Number, and the least Number that can be put for  $n$  is 8: Let therefore  $n = 8$ , and  $x$ , being  $= \frac{19n+1}{9}$ , must be 17; therefore the first

Number, being  $28x$ , will be 476. Again, let  $\frac{19y-1}{28} = n$ , then  $y = \frac{28n+1}{19}$ ; suppose

$\frac{9n+1}{19} = p$ ; then is  $n = \frac{19p-1}{9}$ , and  $\frac{p-1}{9}$  is ei-

ther a whole Number or nothing; let  $p - 1 = 0$ , and  $p = 1$ ; then  $n = \frac{19p-1}{9} = 2$ , and  $19y = 28n$

+



+ 1 = 57. Therefore the two Numbers that were to be found are 476 and 57. And because the Number 476, divided by 19, leaves 1, if it be multiplied by any Number less than 19, and the Product be divided by 19, there will remain the Number which multiplies it. In like Manner, because 57, divided by 28, leaves 1, if 57 be multiplied by any Number less than 28, and the Product be divided by 28, there will be left that Number which multiplied 57. Hence we draw this general Rule, for finding the Year of the *Dionysian* Period. Multiply the *Cycle* of the Sun by 57, and the *Cycle* of the Moon by 476; divide the Sum of the Products by 532; the Remainder, after the Quotient, will be the Year of the *Dionysian* Period.

BESIDES the *Cycles* of the Sun and Moon, there is another Period of Years, which is called the *Cycle* of Indictions, which the *Romans* used, and has no Connection with the celestial Motions, but is a Revolution of 15 Years, which being compleated, it begins again. It is frequently mentioned in the *Imperial* and *Pontifical Diploma's*. The Year before the Birth of *Christ*, the Indiction was 3; and therefore, if to the Year of *Christ* you add 3, and divide the Sum by 15, the Remainder shews the Year of the Indiction. If there be no Remainder, the Indiction is 15.

OF these three *Cycles* of the Sun, Moon, and Indiction, by their mutual Multiplication, the *Julian* Period of 7980 Years is composed. This Period had its Beginning 764 Years before the Creation, and is not yet compleated; and therefore it comprehends all other *Periods*, *Cycles*, and *Epoches* and the Times of all memorable Actions and Histories. There is but one Year in the whole Period, which has the same Numbers for the three *Cycles* of which it is made up; and therefore, if the Historians had remark'd in their Annals the *Cycles* of each Year, there had been no Dispute about the Time of any Action.

THE Year before the Birth of *Christ* was the 4713th Year of the *Julian* Period. And therefore,

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Indictions.The Julian  
Period.From the  
Year of  
Christ to  
find the Ju-  
lian Period.



Lecture XXIX. if to the current Year of *Christ*, we add 4713, the Sum will be the Year of the *Julian* Period: On the contrary, from the Year of the *Julian* Period, subtract 4713, there will remain the Year of the Christian *Æra*.

From the  
Cycles to  
find the Year  
of the *Julian*  
Period.

HAVING the Years of the *Cycle* of the Sun, Moon, and Indiction, to find the Year of the *Julian* Period.

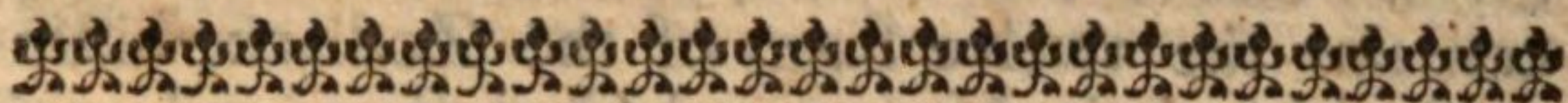
THIS *Problem* may be solved in the same Manner, as we shew'd in the like Case about the *Dionysian* Period, viz. by finding 3 Numbers, such as the first is a Multiple of 19 and 15, or of their Product 285; but being divided by 28, leaves the Number of the *Cycle* of the Sun for a Residue. The second Number must be a Multiple of 28 and 15, or of their Product 420; but being divided by 19, leaves the Year of the *Cycle* of the Moon. Lastly, The third must be a Multiple of 28 and 19; but being divided by 15, leaves the Year of the Indiction: The Sum of these Numbers, if less than 7980, is the Year of the *Julian* Period. But if the Sum be bigger, divide by 7980, and the Remainder will be the Year of the Period required.

THE *Problem* may likewise be solved by constant and stated Multipliers, the first of which is a Multiple of the Number 285; but divided by 28, leaves 1. The second is a Multiple of 420, but divided by 19, leaves 1 for a Residue. The third is a Multiple of 532, but being divided by 15, leaves for a Remainder 1. These Numbers are to be found, by the same Method we shew'd in our former *Problem*, concerning the *Dionysian* Period, and are 4845, 4200, 6916; which being once found, the Canon, or Rule for finding the Year of the *Julian* Period from the Years of the *Cycles*, is this; multiply the Number 4845, by the Year of the *Cycle* of the Sun, and the Number 4200 by the Year of the *Cycle* of the Moon, likewise the Number 6916, by the Year of the Indiction. Divide the Sum of these Products by 7980, neglecting the Quotient, the Remainder will be the Year of the *Julian* Period required. Example: In the Year 1719, the Year of the *Cycle* of the Sun



Sun is 19, of the Moon 9, and of the Indiction 11; multiply 4845 by 19, the Product is 92055; and 4200 being multiplied by 9, the Product is 37800; and lastly, 6916 being multiplied by 11, the Product is 76076. The Sum of the Products is 205931; which, being divided by 7980, will have a Remainder of 6431 Years, which is the Year of the *Julian* Period.

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XXX.



## LECTURE XXX.

*An Appendix, containing a Description and Use of both the Globes; together with some Spherical Problems that are to be solved by a Trigonometrical Calculation.*



OF the Things which pertain to the Globes, some are common to both Globes, some are peculiar to one of the two: And those Things that are common, are either without the Surface, or painted on the Surface. Without the Surface of the Globes, are to be seen,

FIRST, The two Poles, about which the Globes revolve: The one is the *Arctick* Pole, named so from the two Bears that are nigh to it, and is called likewise the *Septentrional* or *North Pole*, from the *Septem Triones*, or the seven Stars of *Charles's Wain*: The other opposite to it, is called the *Antarctick* Pole.

SECONDLY, The *Brazen Meridian*, and one Side of it only, which is distinguished and divided into Degrees, and which, passing through the Poles, represents the true Meridian; and this Side is always to be turned to the East, and the *North-Pole* to the North. The *Meridian* is divided into four



Lecture four Quadrants of 90 Degrees, two of which are  
 XXX. reckoned from that Part of the Equinoctial that is  
 above the Horizon, towards each of the Poles; the other two Quadrants have their Divisions of 90 Degrees, beginning at the Poles, and ending in the Æquator.

THIRDLY, the wooden Horizon, whose upper Side does only represent the Horizon, and is divided into several Circles, the innermost of which contains the twelve Signs of the Zodiack, distinguished by their Names and Characters, and each Sign is divided into 30 Degrees. Next to this are join'd two Circles, with the *Julian* and *Gregorian* Kalendars, disposed according to their Months and Days. The outermost is a Circle with all the Points of the Compass, and the Winds, as they are denominated by the Sea-men.

FOURTHLY, a Brass Quadrant of Altitude, whose Edge is divided into Degrees, and is to be fasten'd to the Meridian at the 90th Degree from the Horizon; from which the Degrees are number'd upon it upwards to the Zenith.

FIFTHLY, The Horary Circle divided into twice twelve Hours: The 12th Hour at Noon is upon the upper Part of it at the Meridian, and the 12th at Night is on the Meridian at the lower Side towards the Horizon. The Pole carries round the Hand which shews the Hour, and is in the Center of the Circle: The Hours upon the East Side of the Meridian are the Morning Hours; these on the West Side are the Hours after Noon.

SIXTHLY, The Mariner's Compass is fixed upon the Pediment or wooden Frame, which contains the Globe; and by it the Globe is put in a right Position, in respect of the Points of the Heavens.

SEVENTHLY, The Semicircle of Position, whose Extremities are fixed to the Points of North and South, so that the Semicircle can be moved freely from the Horizon to the Meridian, and may be raised to any Position. These Things we have described



described are without the Globe. But on the Sur-  
faces are delineated the Things following : Lecture  
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FIRST, The equinoctial Circle divided into 360 Degrees; the Numbers begin at the vernal Intersection, or at first of ♈, and are continued till they return to the same.

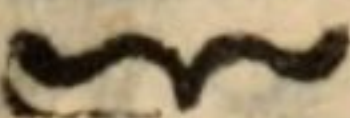
SECONDLY, The Ecliptick, divided into 12 Signs, and each Sign into 30 Degrees, their Names, Characters, and Order are to be learned: they are,

|                                    |                                             |                                     |
|------------------------------------|---------------------------------------------|-------------------------------------|
| ♈                                  | ♉                                           | ♊                                   |
| <i>Aries</i> , or the <i>Ram</i> . | <i>Taurus</i> , or the <i>Bull</i> .        | <i>Gemini</i> , or                  |
|                                    | ♋                                           | ♌                                   |
| the <i>Twins</i> .                 | <i>Cancer</i> , or the <i>Crab</i> .        | <i>Leo</i> , the <i>Lion</i> .      |
| ♍                                  | ♎                                           | ♏                                   |
| <i>Virgo</i> , the <i>Virgin</i> . | <i>Libra</i> , the <i>Balance</i> .         | <i>Scorpius</i> , the               |
| ♐                                  | ♑                                           | ♒                                   |
| <i>Scorpion</i> .                  | <i>Sagittarius</i> , the <i>Archer</i> .    | <i>Capricornus</i> , the            |
| ♓                                  | ♈                                           | ♉                                   |
| <i>Goat</i> .                      | <i>Aquarius</i> , the <i>Water-bearer</i> . | <i>Pisces</i> , the <i>Fishes</i> . |

THE Sun in his annual Motion passes through the Ecliptick, and if we add to it a broad Space of about eight Degrees on each Side, we have the Zodiack, in which are the 12 *Asterisms* or Constellations, the most of which have the Likeness of some living Creature; upon which Account the Zodiack has its Name. In this broad Circle the Moon, and all the Planets perform their Motions: The Ecliptick is to be distinguished from the Equinoctial Circle by this, that the Equinoctial, while the *Globe* is turned, does always cut the Meridian and the Horizon in the same Points. But the Ecliptick constantly changes its Position; sometimes, while the *Globe* is turning, it is high, sometimes it is low; sometimes it cuts the *Æquator* and the Horizon in one Degree, sometimes in another.

THIRDLY, There are two Tropicks of ♋ and ♑, which are the Limits or Boundaries of the Sun's Deviations from the Equinoctial, either towards North or South, including between them  
the



Lecture the oblique Course of the Sun, that is, the Ecliptick, and may be called the outermost of the Sun's  
 XXX.  Parallels. For because the Sun every Day passes to a different Degree of the Ecliptick in its annual Motion, that Degree with the Sun in it, being carried round the Earth, by the diurnal Revolution of the Heavens, will describe a Circle parallel to the *Æquator*; and then there must be so many Parallels, as there are Days from the longest to the shortest; tho' the Sun does not remain for a Day in one Point of the Ecliptick, but is continually advancing forward; and therefore does not describe a perfect Parallel, but rather a spiral Line: But the Distance between each Spire being but very small, especially near the Tropicks, we may well suppose the single Revolutions, but especially the outermost, to be Parallels; which is sufficient for common Use, and is most convenient.

FOURTHLY, The two polar Circles, the Arctick and Antarctick, which have been explained in our VII and XVIII *Lectures*. These Things we have here mention'd, are common to both *Globes*, tho' the Ecliptick and the Semicircle of Position do properly belong only to the celestial *Globe*; yet they are put upon the terrestrial *Globe* also, that the *Phænomena*, which depend upon the Motion of the Sun, and the Points or Cusps of the Houses, may be thereby explain'd, if needful.

THOSE Things which are peculiar or proper to one Sort of *Globe*, are partly some Circles or curve Lines; as in the celestial *Globe*, the two *Colures*, and the *Circles* of *Latitude*; in the terrestrial, the Meridians, Parallels and Rhumbs: partly the Representations in the terrestrial *Globe*, of Seas, Islands and Countries, which we leave to the Geographers to describe. In the celestial *Globe* the Figures of the Constellations are painted, and the Stars represented in the same Order, Magnitude and Position, they have in the Heavens. These we have enumerated in our VI. *Lecture*.

HAVING



HAVING described the *Globes*, we come now to shew their Use, which is manifold; but for our present Purpose, it is chiefly contained in the following *Problems*. Lecture XXX.

**PROBLEM I.** *Having a Place in the terrestrial Globe, to find its Longitude and Latitude.*

TURN the *Globe* till the Place comes to the Meridian (I mean to the Eastern Side of the Brass Meridian); and the Degree of the *Æquator*, which is then under the Meridian, whatever Number it is mark'd by, shews the Longitude of the Place; then upon the Meridian, count up from the *Æquator* the Degrees mark'd, till you come to the Place, and you have the Latitude; which will be North Latitude, if the Place be on the North Side; or Southern, if it lies upon the Southern Side of the *Æquator*.

**PROBLEM II.** *Having the Longitude and Latitude, to find out the Place on the terrestrial Globe, to which they belong:* Seek in the *Æquator* the Degree of Longitude that is given, and bring it to the Meridian; then count from the *Æquator* on the Meridian, the Degree of Latitude given, towards the Arctick or Antarctick Pole, according as the Latitude is either North or South, and under that Degree of Latitude lies the Place that was to be found.

**PROBLEM III.** *To rectify both Globes, and set them to a given Latitude or Elevation of the Pole; and to apply the Quadrant of Altitude to the Vertical Point; and to place the Globes according to the Points of the Compass, by Help of the Needle.* If the Latitude of the Place be North, raise the Arctick Pole above the Horizon; but for a South Latitude, you must raise the Antarctick: Then from the elevated Pole, count upon the Meridian towards the Horizon, the Degrees of the Poles Elevation; and that Point where the Reckoning ends, bring to the Horizon, and then the *Globe* is adjusted to a due Elevation. Count from the *Æquator* on the Meridian the Latitude required, and there will be the Vertex of the Place, or the Zenith.



Lecture  
XXX.

To this Point of the Meridian fasten the Quadrant of Altitude, with the Screw that is at the End of it, so that the Edge of the Quadrant, which is divided into Degrees, may be join'd to this Point. *Lastly*, Turn the whole Frame in which the *Globe* is with its Pediment, till the magnetick Needle lie in the Plane of the Meridian, so that the North Point of the Horizon of the *Globe* be turn'd Northwards; then will the rest of the Points on the Horizon of the *Globe* agree with the corresponding Points of the Horizon of the Place.

**PROBLEM IV.** *To find for any Day of the Year the Degree or Place of the Sun in the Ecliptick, by the Help of the Kalendar, and the Circle of Signs adjoin'd; and then to mark it upon the Ecliptick.* Seek in the wooden Horizon, the Month and Day given; but take care to distinguish the *Julian* and *Gregorian* Kalendars, that you may not mistake the one for the other: Then in the innermost Circle, which is the Circle of Signs, over-against the Day, you will see the Degree and Sign in which the Sun is that Day. In the Ecliptick which is drawn upon the Surface of the *Globe*, seek first the Sign, and then the Degree of the Sun's Place. The Place of the Sun is more accurately found out by an *Ephe-meris*, which is made for each Year, or else it may be calculated by *Astronomical* Tables.

**PROBLEM V.** *To find the right Ascension and Declination of the Sun, or any Star; and by that Means to adjust the Hand which points the Hours to the twelfth Hour.* Bring the Sun's Place in the Ecliptick, found by the last *Problem*, to the Meridian, and mark the Degree of the *Æquator* which is then under the Meridian, that will be the right Ascension of the Sun: Then compute from the Equinoctial on the Meridian, the Number of Degrees to the Place of the Sun; they will shew the Sun's Declination, which will either be North or South, as the Sun is on this or the other Side of the *Æquator*. When the Place of the Sun is in the Meridian, turn the Hour-hand upwards, till it comes to the twelfth Hour at Noon. After the same Manner bring the Place of  
any



any fixed Star to the Meridian, and you shall find its right Ascension on the *Æquator*, and its Declination on the Meridian. Having the Place of the Sun, we shew'd how to find its right Ascension and Declination by *Trigonometry* in our XIX. *Lecture*. Lecture XXX.

**PROBLEM VI.** *To find the Meridian Altitude of the Sun, or any fixed Star, by a Quadrant, or any other Instrument fit for the Purpose.* We shew'd the Method of observing the Sun's or a Star's Altitude in *Lecture XIX*.

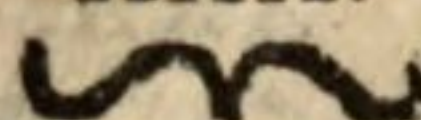
**PROBLEM VII.** *Having the Declination and Meridian Altitude of the Sun, or of a fixed Star, to find the Latitude of the Place or Height of the Pole above the Horizon.* The Method of finding the Latitude by Observation was likewise explain'd in *Lecture XIX*.

**PROBLEM VIII.** *Having the right Ascension of the Sun, and of a fixed Star, to find the Time when the Star culminates or comes to the Meridian.*

**SUBTRACT** the right Ascension of the Sun from the right Ascension of the Star, adding, if needful, 360 Degrees; and there will remain the Arch of the *Æquator*, that has passed the Meridian between Noon and the Time of the Culmination: Turn this Arch into Time by dividing the Degrees by 15, and the Quotient gives the Hours; then multiply the remaining Degrees by 4, and you have the Minutes; and likewise divide the Minutes, which are the Parts of Degrees, by 15, and the Quotient gives the horary Minutes: And if there be any Minutes of Degrees remaining after the Division, multiply them by 4, and you have the horary Seconds: The Time made up of these Hours, Minutes and Seconds, shews the Moment of the Culmination of the Star.

**PROBLEM IX.** *Having the Place of the Sun, or any Star, to find its oblique Ascension and Descension; as also its Eastern and Western Amplitude.* Bring the Place of the Sun or Star to the Horizon in the East, and mark the Point of the *Æquator* that riseth with it; it will be its oblique Ascension:



Lecture XXX.  sion: Then count from the Point of East upon the Horizon, to the Place of the Sun or Star; the Degrees intercepted will be the Eastern Amplitude. If you bring the Place of the Sun or Star to the Western Side of the Horizon, the Degree of the  $\text{\AA}$ equator which goes down with it, is the oblique Descension; and the Arch of the Horizon between the West Point, and the Place of the Sun or Star, is the Western Amplitude.

Ta. XXVII. Fig. 2. THE *Trigonometrical* Solution of the *Problem* is this: Let  $\text{HPOP}$  be the Meridian,  $\text{\AA Q}$  the  $\text{\AA}$ equator,  $\text{P}$  the Pole,  $\text{S}$  the Sun, or Star in the Horizon, whose Declination is  $\text{SR}$ ; or the Point of East or West. In the right-angled Triangle  $\text{orRS}$ , we have the Side  $\text{RS}$  the Declination of the Sun or Star, and the Angle  $\text{RorS}$ , which the  $\text{\AA}$ equator makes with the Horizon, and is equal to the Complement of the Latitude; whence we shall find the Arch  $\text{orR}$ , which is the Ascensional Difference of the Sun or Star; which, added to the Right Ascension, or subtracted from it, according as the Sun or Star is towards the depressed or elevated Pole, gives the oblique Ascension. We shall have moreover in the same Triangle, the Arch  $\text{orS}$ , the Amplitude of the Sun or Star. The Ascensional Difference added to a Quadrant, or subtracted from it, according as the Sun or Star is towards the elevated or depressed Pole, gives the Semidiurnal Arch; which being turned into Time, shews the Time of half the Stay of the Sun or Star above the Horizon.

PROBLEM X. *Having the Ascensions of the Sun or Star, both Right and Oblique, to find the half Time of their Stay above the Horizon: As also the Length of Day and Night, and the Time of Sun-rising and setting.* Take the Difference of the Oblique and Right Ascension, and we shall have the Ascensional Difference: Convert it into Time, as we shew'd in the VIIIth Problem, which, when the Sun or Star declines to the elevated Pole, is to be added to six Hours; but if to the depressed Pole, it is to be subtracted from six Hours; and we shall have half the Time of the Stay of the Sun or Star  
above



above the Horizon: And its Complement to 12 Hours, is half the Time it abides under the Horizon. Lecture XXX.  
 Half the Time of the Sun's Stay above the Horizon, being computed from Noon, gives the Time of Sun setting; and half the Time of the Sun's Stay under the Horizon, computed from Midnight, gives the Hour of the Sun's rising; and the half Time of the Sun's Stay above the Horizon being doubled, gives the Length of the Day; and the half Time of the Stay below the Horizon doubled, gives the Length of the Night. If you put the Hour-hand to the 12th Hour, when the Place of the Sun is in the Meridian, and turn the *Globe* round, till the Place of the Sun comes to the Eastern Side of the Horizon, the Hand will point out the Hour of Sun-rising: Bring it to the Western Side of the Horizon, and the Hand will shew the Time of Sun-setting; from which it is easy to compute the Length of Day and Night.

**PROBLEM XI.** *Having the Time of the Culmination of a Star, and of its half Stay above the Horizon; to find the Hour of its rising and setting.* If from the Time of the Star's Culmination, you subtract the Time of the half Stay above the Horizon, you will have the Hour wherein the Star riseth: If you add that Time to the Time of the Culmination, you shall have the Time of the Star's setting, which in both Cases is computed from Mid-Day. Or if, when the Place of the Sun culminates, you bring the Hour-hand to the 12th Hour, and then turn round the *Globe*, 'till the Star comes to the Eastern or Western Side of the Horizon, the Hand will point to the Hour of the Rising or Setting of the Star.

**PROBLEM XII.** *To find the Degree of the Ecliptick, which rises or sets with a given Star; and from thence to determine its Cosmical and Achromical rising and setting.* Bring the given Star to the Eastern or Western Side of the Horizon, and mark what Degree of the Ecliptick rises or sets with it; then in the wooden Horizon look for that Sign and Degree which rose or set with the Star; and



Lecture over-against it in the Kalendar, you will find the  
 XXX. Month and Day of the cosmical Rising of the Star.  
 ~~~~~ And if you look in the same Horizon, the Point opposite to the rising Point; over-against it in the Kalendar, you shall have the Month and Day of its cosmical Setting. So likewise, over-against the Degree that sets with the Star, you will find the Day and Month of the achronical Setting; and the opposite Degree will shew in the Kalendar the Day and Month of the Star's achronical Rising.

Ta. XXVII. THE *Trigonometrical* Solution of the *Problem* is
 Fig. 3. this: Let HO be the Horizon, HZO the Meridian, ÆQ the Æ quator, EC the Ecliptick, γ the Point of Intersection of the Equator and Ecliptick; A the Point of the Ecliptick which rises with the Star; and the Point of the Æ quator which rises with the Star, suppose to be or . In the Triangle $\gamma or A$, we have γor the oblique Ascension of the Star; and the Angle γ , the Inclination of the Æ quator and Ecliptick; and the Angle $\gamma or A$, the Height of the Æ quator above the Horizon, or its Complement to two right Angles. Hence we shall find the Arch of the Ecliptick γA , and the Point of it A, which rises with the Star. But by the Kalendar, or an *Ephemeris*, we have the Time when the Sun is in that Point; and therefore, we have the Time when the Star rises cosmically; we have likewise the Angle $\gamma A or$ the Angle of the Ecliptick and the Horizon at the rising Point. When the Sun is in the Point opposite to the Point A, then the Star rises achronically: And by a like Calculation, we shall find the Time when the Star sets cosmically or achronically.

PROBLEM XIII. *Having the Latitude of the Place, and the Degree of the Ecliptick which rises or sets with the Star, to determine the heliacal Rising or Setting of a Star.* Bring the Star to the Eastern Side of the Horizon, and turn the Quadrant of Altitude round to the Western Side, till it cut the Ecliptick in the twelfth Degree from the Horizon, on the Quadrant of Altitude, if the Star be of the first Magnitude. Then mark the Point of the Ecliptick,

Ecliptick, where the Quadrant intersects it; that Point, when the Star rises, is twelve Degrees high above the Western Horizon, but at the same time the opposite Point is twelve Degrees below the Eastern Horizon: Look that Point in the wooden Horizon, and over-against it you will find the Month and Day when the Sun enters that Point of the Ecliptick, which is the Day of the Star's rising heliacally; when it begins to get so far from the Sun's Beams, that it may be seen in the Morning before Sun-rising: but if you would know the heliacal Setting, bring the Star to the West-side of the Horizon, and turn the Quadrant of Altitude to the East side, 'till the twelfth Degree of it from the Horizon cuts the Ecliptick, and mark that Point where it intersects the Ecliptick; the Point opposite to this, is so many Degrees depress'd under the Horizon at the Western Side; and if we find, in the wooden Horizon, the Month and Day when the Sun comes to that Point, we shall have the Time of the heliacal Setting.

By *Trigonometry* the *Problem* is thus to be solved: In the Figure of the preceding *Problem*, let A be the Point of the Ecliptick, which rises with the Star: And suppose the Sun in the Ecliptick at $\odot$, so that the Arch $\odot R$ of the Circle of Depression may be 12 or 13 Degrees, according as the Star is of the first or second Magnitude. In the right-angled Triangle A R $\odot$, we have the Angle R A $\odot$, the Angle of the Ecliptick and Horizon, and the Side R $\odot$, which is 12 or 13 Degrees: Hence we shall have the Side A $\odot$, which, added to ΥA , gives the Arch $\Upsilon \odot$, and the Point $\odot$, which the Sun must be in when the Star rises heliacally. In the same Manner, we may find the Time of the heliacal Setting.

Ta. XXVII.
Fig. 3.

PROBLEM XIV. *Having the Latitude of the Place, and the Place of the Sun in the Ecliptick; to find the Beginning and End of Twilight.* Rectify the *Globe* for the Latitude of the Place by *Problem* third, and put the Hour-Hand to the twelfth Hour, the Sun's Place being in the Meridian;

Lecture then take the Point of the Ecliptick opposite to
 XXX. the Sun's Place, and turn the *Globe* Westward, as
 also the Quadrant of Altitude, 'till the Point opposite to the Sun's Place, cut the Quadrant of Altitude in the 18th Degree above the Horizon: The Hour-Hand will shew the Time of Dawning in the Morning. But if you take the Point opposite to the Sun, and bring it to the Eastern Hemisphere, and turn it 'till it meets with the Quadrant of Altitude in the 18th Degree, the Hand will shew the Hour when Twilight ends in the Evening. The *Trigonometrical* Solution of this Problem is in *Lecture XX.*

PROBLEM XV. *Having the Latitude of the Place, and the Place of the Sun, if we have besides any one of the three following Things, viz. The Hour of the Day or Night, or the Altitude or Azimuth of the Sun or a Star; to find the other two.* Rectify the *Globe* for the Latitude given, and bring the Place of the Sun to the Meridian; and the Hour-Hand to the Twelve o' Clock Hour: Then if the Hour be given, turn round the *Globe* 'till the Hand points to it, and bring the Quadrant of Altitude to the Place of the Sun or Star; you will see in the graduated Edge, the Degree of Altitude; and where the Quadrant intersects the Horizon, there you will find its Azimuth, to be counted from the Intersection of the Meridian and Horizon: But if the Altitude be given, turn the *Globe* with one Hand, and the Quadrant of Altitude with the other, 'till the Place of the Sun meet with the Quadrant at the given Altitude; then the Hand will point to the Hour; and the Intersection of the Quadrant and Horizon will shew the Azimuth. But if the Azimuth be given, turn the Quadrant 'till it intersects the Horizon at the given Azimuth, and there keep it fixed; but turn the *Globe*, 'till the Place of the Sun or Star meets with the Quadrant, and the Degrees upon the Quadrant will give the Altitude, and the Hour-Hand will point to the Hour.

THE

THE *Problem* is solved *Trigonometrically* thus: Let Lecture XXX.
 HO be the Horizon, HPO the Meridian, $\mathcal{A}Q$ the $\mathcal{A}$ equator, Z the Vertex or Zenith, P the Pole, S the Sun or Star, whose Distance from the Vertex is ZS , and SP the Complement of Declination, or its Distance from the Pole. Ta. XXVII
Fig. 4. Because we have the Right Ascensions of the Sun and Star, we have the Difference of their Right Ascensions; which being turned into Time, will shew the Time of the Culmination of the Star; and the Arch which measures the Angle $\mathcal{A}PS$, being turned into Time, will give the Hour of the Night. Now in the Triangle ZPS , having ZP the Distance of the Zenith from the Pole, and PS the Complement of the Declination of the Star; if I have, besides these two, the Angle P , which the Hour gives, we can from them find the Angle Z , which shews the Star's Azimuth, and the Arch ZS the Star's Zenith Distance, which will shew the Altitude. Or if we have the Arch ZS , we shall find the Angle P , and by that the Hour of the Night; as also the Angle PZS the Azimuth. Or if we have the Angle PZS , we can from thence find ZS the Complement of the Altitude, and the Angle ZPS , which will give the Hour. By the same Method, having the Altitude of the Sun, which we take by an Observation; and his Declination, which is known by Tables; from his Place in the *Ec*liptick; we can find the Angle $\mathcal{A}PS$, which being turned into Time, will give the Hour of the Day.

PROBLEM XVI. *To find the Distance between two Places on the Surface of the Terrestrial Globe.*

LET us, for Distinction-sake, call one of the Places the first, and the other the second. Rectify the *Globe*, for the Latitude of the first Place, and bring it to the Meridian, and there fix the *Globe* with the Quadrant of Altitude to the Vertex, and turn the Quadrant till its graduated Edge pass through the second Place: Then count the Degrees of Distance, from the Vertex to the second Place,

Lecture Place: And the Arch of the Horizon intercepted
 XXX. between the Meridian and Quadrant will give you
 the Angle of Position.

Ta. XXVI.
 Fig. 5.

By *Trigonometry* we thus proceed: Let ÆQ be the *Æquator*, P the Pole, S, s two Places, whose Complements of Latitude are PS and Ps ; and because their Longitudes are given, we have their Difference of Longitude, which is measured by the Angle SPs : Therefore in the Triangle SPs , we have the Sides SP, sP , with the Angle SPs : by them we can find Ss in Degrees and Minutes, which being converted into Miles, allowing 69 *English* Miles for each Degree, we shall have their Distance in Miles. We can also find the Angles PSs and PsS , which are the Angles of Position.

In the same Manner in the Heavens, if we have the Right Ascensions and Declinations of two Stars, or their Longitudes and Latitudes, we shall find their Distances.

PROBLEM XVII. *For any Time and Place, to erect the Theme or Scheme of the Heavens.* Rectify the celestial *Globe* for the Latitude of the Place. If you have not a celestial *Globe*, a terrestrial will do. Take the Place of the Sun for the given Time, and bring it to the Meridian, and the Hour-hand to the twelfth Hour; then turn the *Globe*, till the Hand shews the given Hour: Or, if you like to be more accurate in your Work, to the Right Ascension of the Sun, add so many Degrees and Minutes, as the Time from Mid-day requires, for every Hour counting 15 Degrees, and for every four Minutes a Degree, rejecting, if it exceeds it, 360 Degrees; so by this you will have the Right Ascension of Mid-heaven, or the Degree of the Equinoctial, which then culminates, which is to be placed under the Meridian. Then fasten the Semicircle of Position to the Meridian, at the Points of South and North in the Horizon. From the Point of the *Æquator* culminating, count on the *Æquator* 30 Degrees Eastward,

Eastward, and bring the Semicircle of Position to the 30th Degree, and observe in what Degree this Semicircle cuts the Ecliptick; that will be the Cusp of the eleventh House, which must be set down on Paper. Again, move the Semicircle of Position to the 60th Degree of the Equinoctial from the culminating Point, and mark where it cuts the Ecliptick, and you have the Cusp of the twelfth House, which is likewise to be writ down. Bring the Semicircle of Position to the Western Side, and count thirty Degrees from the culminating Point; and letting the Semicircle pass thro' that Point, observe where the Semicircle cuts the Ecliptick; that will be the Cusp of the ninth House. Then count from the culminating Point again Westward 60 Degrees, and the Semicircle of Position, passing thro' that Point, will cut the Ecliptick in the Cusp of the eighth House: And the Meridian cuts the Ecliptick in the Cusp of the tenth House. And the Place where the Horizon Eastward cuts the Ecliptick, is the Cusp of the first House, or the *Horoscope*; and the Western Side of the Horizon shews in the same Ecliptick, where it cuts it, the Cusp of the seventh House: And as it is diametrically opposite to the first; so is the second to the eighth; and the third to the ninth; the fifth to the eleventh; and the sixth to the twelfth.

PROBLEM XVIII. *Having erected the Theme, to direct any Point to any other Point.* To a Planet or Aspect assign its Place in the Zodiac, according to its Longitude and Latitude; and chuse any Planet or Degree of the Ecliptick, which you would direct, and which, for Distinction sake, we will call the first Place; and the Place to which you would direct this first Place, call the second; then thro' the first Place, which used to be called the Significator, draw the Semicircle of Position, and mark that Degree in which it cuts the *Æquator*; then, keeping the Semicircle in the same Position, turn the Globe Westward,

Lecture ward, 'till the second Place arrive at it; and then
 XXX. again observe where the Equinoctial is cut by the
 said Semicircle. Subtract the Degree first obser-
 ved, from the Degree observed in the second;
 adding, if need be, 360 Degrees; the Remainder is
 the Arch of Direction, which was to be found.

F I N I S.

N. B. *There is no Plate XVIII.*



TH



T H E I N D E X,

Which sheweth where the Terms and
Words used in *Astronomy* are explain-
ed in this BOOK.

A.



BSIDS, See *Apsides*.

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